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RELEASE OF POTASSIUM BY 18 ONTARIO SOILS DURING CONTINUOUS CROPPING IN THE GREENHOUSE[1]

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[Received for publication June 7, 1956]

ABSTRACT

Eighteen Ontario soils were ranked according to their capacity to supply potassium from non-exchangeable forms to eight successive crops of alfalfa. This capacity was found to be closely related to the percentage of clay in the soils. Potassium content of the alfalfa and total uptake of potassium were highly correlated with both exchangeable soil potassium and release of potassium from non-exchangeable forms. Exchangeable potassium levels below 100 lb. per acre gave low yields and potassium content of the crop. Excessively high exchangeable potassium levels resulted in luxury consumption of potassium by the crop or in fixation by the soil. In soils at or near their equilibrium exchangeable potassium levels, i.e., not heavily fertilized, there was a close relationship between potassium-supplying power and the exchangeable potassium content measured either before cropping commenced or at the end of the cropping period.

Numerous investigators have shown that the amount of exchangeable potassium in a soil at any time is not always a reliable measure of the capacity of the soil to supply potassium to a crop for an extended period. The average exchangeable potassium content of soil samples taken by the Ontario Soil Survey from unfertilized, permanent pasture fields in Ontario ranges from 60 to 375 lb. of K per acre in the top 6 inches (6). The exchangeable potassium contents of these soils should represent their equilibrium levels of exchangeable potassium. In spite of the fact that in some instances a crop may take up more potassium than was initially present in exchangeable form in the soil, no response to potassium fertilization may be obtained. It is apparent that such soils must release appreciable amounts of potassium from non-exchangeable forms during the growing period of the crop. The objective of this study was to determine the relative capacities of several soils to release non-exchangeable potassium to successive crops of alfalfa grown in the greenhouse.

It was recognized that plant species differ in their capacity to extract nutrient elements from soil. Moreover, in transferring the soils to the greenhouse and in screening out the coarsest particles, the soils were altered appreciably. It was considered possible, however, to obtain a measure of the relative amount and rate of release of non-exchangeable potassium, i.e. the potassium-supplying power of the soils.

[1] Contribution from Department of Soils, Ontario Agricultural College, Guelph, Ont.
[2] Lecturer, and Professor of Soils, respectively.

MATERIALS AND METHODS

Samples of 16 soils were taken from pasture fields that had not been fertilized recently. Samples of 2 additional soils, Dumfries and Brighton, were taken from pasture fields that had been heavily fertilized previously. Sampling was done to the depth of the cultivated layer. The soils were passed through a 4-mesh sieve and particles remaining on the screen were discarded. Lime was supplied to the acid Saugeen, Brookston and Fox soils by adding C. P. calcium carbonate. The amount of lime required to bring the pH to 7.0 was determined by the method of Dunn (5). Phosphate was supplied as 20 per cent superphosphate applied at the rate of 2000 lb. per acre. Nitrogen was added in solution as ammonium nitrate to supply 100 lb. of N per acre. Additional nitrogen and phosphorus were supplied after the first crop by adding ammonium phosphate at the rate of 100 lb. per acre. After the fifth crop, another 90 lb. of P_2O_5 per acre were added as mono-calcium phosphate in solution. No potassium fertilizer was applied. Optimum moisture was maintained by regular weighings and additions of water as required.

Inoculated Dupuits alfalfa was seeded in each pot containing 8 to 10 lb. of soil, depending upon the soil texture. After emergence the seedlings were thinned to four plants per pot. Each soil was replicated three times and, at each watering, the pots were rotated on the benches so that all were subjected to nearly identical light and temperature.

The alfalfa tops were harvested, dried and weighed every month when most of the pots contained plants in the bloom stage. As the experiment progressed, the alfalfa on some of the less productive soils had not reached the bloom stage when harvested. All pots were harvested on the same day at each clipping. After the eighth crop, the roots were removed from the pots, washed and weighed separately. The total period of cropping was 273 days.

The harvested plant material was analysed for potassium by a dry-ashing procedure with the potassium in the solution being determined by means of a Barclay flame photometer.

The initial exchangeable potassium content of the soils was determined by the neutral normal ammonium acetate method as described by Peech (8) and by the PS_o method developed in this laboratory. The latter method employs a solution of 0.1 N ammonium acetate and 0.05 N sulphuric acid, a 1 : 10 soil : solution ratio, and 15 minutes extraction time. The potassium in the extract was measured by the Barclay flame photometer. Soil samples were taken from the pots after every second crop was harvested and were analysed for exchangeable potassium by the PS_o method. Thus it was possible to calculate (1) the total potassium removed in the tops and roots, (2) the decrease in exchangeable potassium content of the soils, and (3) the amount of non-exchangeable potassium released during the cropping period.

The cation exchange capacity, exchangeable calcium and magnesium of the soils before and after cropping were determined by the methods of Peech (8). The organic matter contents before and after cropping were determined according to Walkley's modification of the Schollenberger method (10). The pH of the soils was determined by the glass electrode in a 1 : 1 soil : water mixture.

RESULTS

The lime treatment had increased the pH of the acid Saugeen, Brookston and Fox soils to 7.0 by the end of the cropping period; the exchangeable calcium content was increased accordingly. There were no appreciable changes in organic matter content, cation exchange capacity, exchangeable calcium and magnesium, or pH in the remaining soils during the cropping period.

The initial exchangeable potassium values of the soils, shown in Table 1, as determined by two methods, covered a wide range. Many of the soils had exchangeable potassium contents quite similar to the average equilibrium contents determined in another study (6) and also shown in Table 1. The Dumfries and Brighton soils, however, contained exchangeable potassium much in excess of their respective average equilibrium values as a result of potassium fertilization.

TABLE 1.—AVERAGE EQUILIBRIUM AND INITIAL EXCHANGEABLE POTASSIUM CONTENTS AND CHANGES DURING CROPPING OF 18 ONTARIO SOILS

(Lb. of K per acre)

Soil type	Average equilibrium exch. K content[1]	Initial exch. K content		Exch. K. content[3] after crop number			
		NH_4 Ac method[2]	PS_u method[3]	2	4	6	8
Haldimand clay loam	290	413	390	290	199	178	138
Brookston clay	280	415	356	310	312	254	242
Saugeen silty clay	110	397	347	228	153	172	138
Huron clay	234	327	266	242	192	204	172
Schomberg silty clay	220	282	232	206	176	174	153
Bondhead loam	138	262	246	138	116	116	100
Vineland loam	130	72	68	56	53	52	36
Honeywood silt loam	182	202	198	83	60	77	57
Dundonald loam	78	153	140	92	85	77	63
Otonabee loam	160	149	131	110	108	93	80
Harriston loam	168	212	193	134	102	100	86
Percy loam	111	127	108	68	72	58	48
Dumfries sandy loam	135	558	513	231	166	144	138
Burford clay loam	141	115	112	84	77	74	61
Guelph loam	160	92	79	86	82	86	63
Pontypool sandy loam	88	143	129	75	66	52	43
Brighton loamy sand	90	315	316	236	168	85	67
Fox loamy sand	81	33	33	34	34	31	25

[1] Jeyaseelan (6)
[2] Peech *et al.* (8)
[3] Extractant—0.1 N NH_4Ac + 0.05 N H_2SO_4; 1 : 10; 15 min.

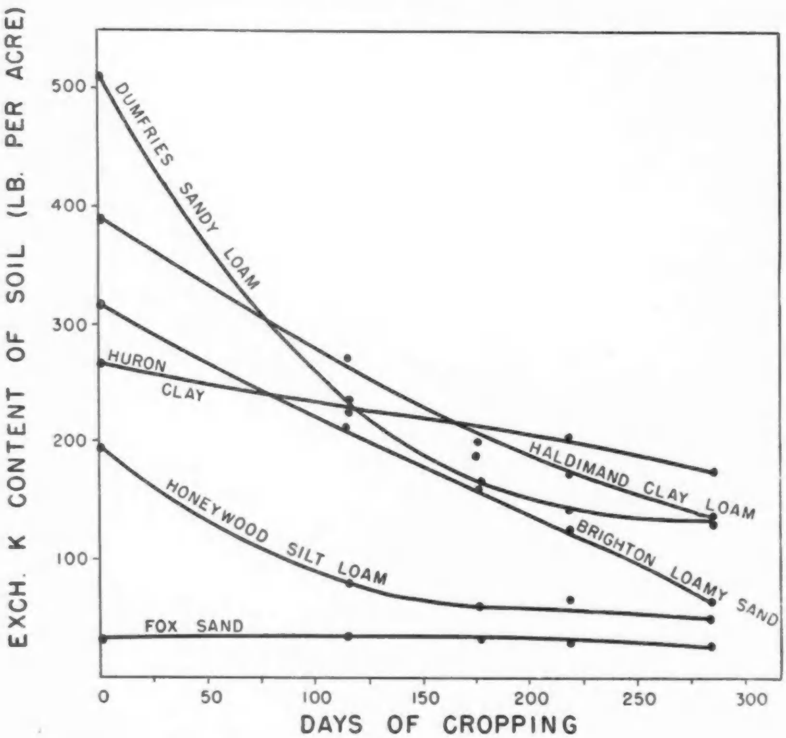

FIGURE 1. Changes in exchangeable potassium content of soils with continuous cropping.

On the basis of the levels of exchangeable potassium, the Dumfries loam should have produced highest yields but it was, in fact, fifth in crop-producing capacity; the Brighton loamy sand ranked fifth in exchangeable potassium but was sixteenth in crop-producing capacity. Considering the other sixteen soils, however, the coefficient of correlation of initial exchangeable potassium with total yield of eight crops of alfalfa was 0.80^{++}.*

The exchangeable potassium contents of the soils after the second, fourth, sixth and eighth crop, also shown in Table 1, indicated a continual decrease during cropping. There was, however, considerable variation in the rate of decrease in exchangeable content as illustrated in Figure 1 for selected soils. The Dumfries soil, for example, had an artificially high exchangeable potassium level initially but this level was reduced rapidly. The Huron soil, on the other hand, with an initial exchangeable potassium level similar to its equilibrium value showed much less reduction during cropping. It will be shown later that the Huron soil had a much greater potassium-supplying power, thus enabling it to maintain a higher level of exchangeable potassium under intensive cropping.

*Throughout this paper, ++ after a correlation coefficient indicates that it is significant at the 1 per cent level; + indicates that it is significant at the 5 per cent level.

The total amount of potassium released from non-exchangeable forms by a soil was calculated by subtracting the decrease in exchangeable potassium content from the total amount of potassium in the plants produced by that soil. The non-exchangeable potassium released to two, four, six, and eight crops of alfalfa is reported in Table 2. The Dumfries and Brighton soils which contained abnormally high levels of exchangeable potassium showed a negative release, i.e., conversion of exchangeable potassium to non-exchangeable forms, during the first part of the cropping period. When the data for these two soils were omitted, however, the coefficient of correlation of total yield of the eight crops and non-exchangeable potassium released was 0.69^{++}.

TABLE 2.—TOTAL YIELD OF ALFALFA AND POTASSIUM AND CUMULATIVE AMOUNTS OF OF NON-EXCHANGEABLE POTASSIUM RELEASED BY 18 ONTARIO SOILS DURING CROPPING

Soil type	Total yield dry matter (t./ac.)	Total yield of K (lb./ac.)	Non-exchangeable K (lb./ac.) released to			
			2 crops	4 crops	6 crops	8 crops + roots
Haldimand clay loam	17.0	611	107	165	258	359
Brookston clay	12.6	442	28	155	177	328
Saugeen silty clay	18.8	520	74	135	239	311
Huron clay	15.6	404	94	148	252	310
Schomberg silty clay	15.3	352	86	143	217	273
Bondhead loam	18.0	313	31	84	134	167
Vineland loam	10.4	187	62	111	144	155
Honeywood silt loam	17.0	273	27	77	125	132
Dundonald loam	11.6	197	32	74	101	120
Otonabee loam	10.4	146	23	63	80	95
Harriston loam	13.5	200	9	35	65	93
Percy loam	10.6	151	42	80	83	91
Dumfries sandy loam	17.7	462	−81	−30	26	87
Burford clay loam	11.1	130	20	46	67	79
Guelph loam	7.7	93	29	45	74	77
Pontypool sandy loam	10.9	148	15	44	51	62
Brighton loamy sand	8.7	305	−9	13	0	56
Fox loamy sand	3.1	31	11	17	20	23

TABLE 3.—POTASSIUM CONTENT AND YIELDS OF TOPS OF ALFALFA DURING CROPPING ON 18 ONTARIO SOILS[1]

Soil Type	1st Crop		2nd Crop		3rd Crop		4th Crop		5th Crop		6th Crop		7th Crop		8th Crop	
	Dry wt.[2]	% K	Dry wt.	% K	Dry wt.	% K	Dry wt.	% K	Dry wt.	% K	Dry wt.	% K	Dry wt.	% K	Dry wt.	% K
Haldimand	6.44	2.58	7.22	2.95	6.57	2.20	6.48	1.99	5.52	2.05	4.96	1.93	4.82	1.46	4.03	1.53
Brookston	1.97	2.68	4.68	1.75	5.87	2.36	4.85	2.30	4.34	1.82	3.85	1.77	4.43	2.05	4.18	2.33
Saugeen	7.69	2.21	7.36	2.46	8.92	1.65	7.76	1.32	5.29	1.42	5.30	1.47	4.94	1.25	5.21	1.17
Huron	5.86	1.64	6.09	1.97	6.27	1.62	6.52	1.37	5.66	1.57	5.19	1.47	4.10	1.25	4.44	1.17
Schomberg	6.39	1.57	5.91	1.76	6.94	1.32	5.34	1.29	5.33	1.36	4.73	1.37	3.60	1.10	3.28	1.18
Bondhead	9.46	1.67	7.76	1.61	9.59	0.98	6.55	0.91	6.67	0.89	5.37	0.81	3.58	0.71	3.74	0.69
Vineland	7.18	1.27	5.54	1.40	7.21	1.05	4.39	0.95	4.73	0.97	3.54	0.91	1.98	0.77	2.55	0.80
Honeywood	10.77	1.50	7.12	1.37	8.27	0.79	5.30	0.62	5.37	0.55	4.78	0.58	2.78	0.54	3.13	0.45
Dundonald	5.75	1.66	6.03	1.43	6.86	1.04	4.58	0.87	4.83	0.91	4.07	0.93	3.00	0.76	2.55	0.78
Otonabee	4.31	1.13	3.75	1.07	4.86	0.98	4.62	0.84	4.10	0.97	4.53	0.54	3.16	0.46	3.56	0.50
Harriston	5.25	1.24	5.05	1.46	5.77	1.36	4.68	0.83	4.58	0.78	4.26	0.70	3.60	0.60	3.49	0.68
Percy	7.85	1.23	6.59	1.22	6.97	0.75	4.36	0.58	3.64	0.63	2.79	0.60	2.11	0.51	2.33	0.56
Dumfries	8.65	2.24	8.39	2.58	9.45	1.66	5.93	1.34	7.65	1.30	4.60	1.31	4.01	0.93	3.36	1.02
Burford	5.90	0.90	4.34	1.03	5.93	0.68	4.71	0.57	3.55	0.67	4.19	0.62	2.77	0.54	3.01	0.59
Guelph	4.90	0.86	2.90	0.83	2.63	0.75	3.18	0.66	3.12	0.77	3.50	0.77	2.21	0.71	3.13	0.73
Pontypool	5.02	1.70	6.14	1.27	6.57	0.80	4.51	0.75	4.29	0.66	2.99	0.69	1.86	0.57	2.02	0.55
Brighton	2.37	2.47	3.46	2.99	4.51	2.32	4.78	2.04	4.23	2.11	3.64	1.85	2.48	1.47	3.24	1.73
Fox	2.43	0.49	1.73	0.65	1.40	0.52	1.09	0.49	1.03	0.63	1.39	0.58	0.86	0.60	1.06	0.55

[1] Average of 4 replications
[2] All dry weights are expressed in grams of oven-dry alfalfa per pot.

Uptake of Potassium

It is evident from Table 3 that soils having high initial exchangeable potassium levels, above 300 lb. of K per acre, produced alfalfa with high content of potassium, greater than 2 per cent, although actual yield of alfalfa was not necessarily greater than on other soils. This is evidence of luxury consumption of potassium. The total potassium taken up in the tops and roots, shown in Table 2, was highly correlated with initial exchangeable potassium levels, $r = 0.90^{++}$. When the data for the Dumfries and Brighton soils were omitted, $r = 0.96^{++}$.

Although there was some potassium fixation by the Dumfries and Brighton soils during the early stages of cropping, there was a high degree of correlation between total non-exchangeable potassium released by all 18 soils during the entire cropping period and the total potassium contained in the tops and roots, $r = 0.92^{++}$. Again, when the Dumfries and Brighton soils were omitted, $r = 0.96^{++}$. The amount of non-exchangeable potassium released ranged from 23 to 359 lb. of K per acre.

The actual percentage of potassium in any crop was highly correlated with the exchangeable potassium content of the soil immediately preceding

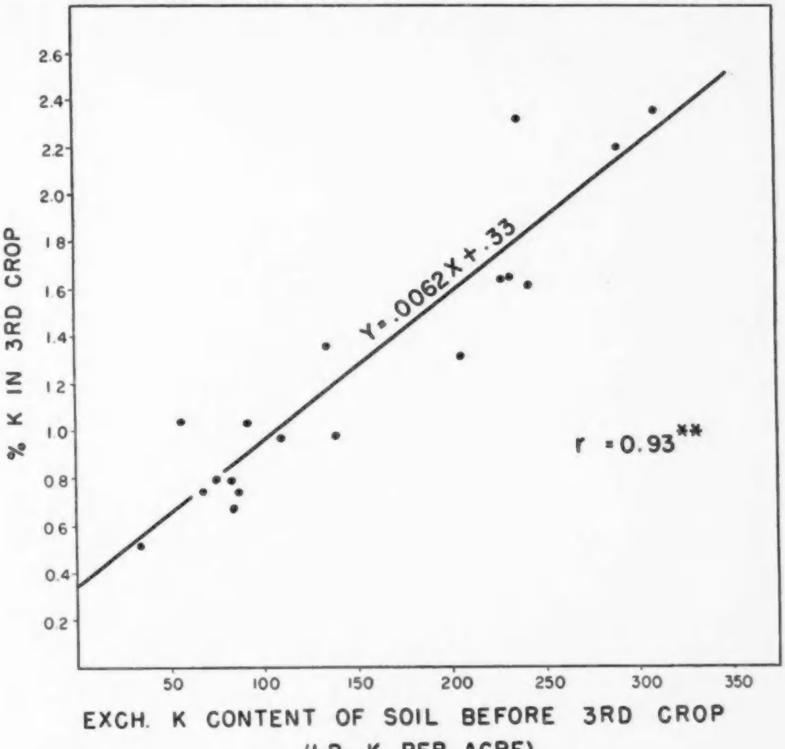

FIGURE 2. Relationship between exchangeable potassium in soil and potassium content of alfalfa tissue.

the growth of the crop. The regression line shown in Figure 2 indicates that when the exchangeable potassium level was about 100 lb. of K per acre, the potassium content of the crop was about one per cent. Moreover, when the potassium content of the crop fell below one per cent, there was a marked decrease in yield of the subsequent crop (Table 3). This latter observation has also been made by Bear *et al.* (1). Potassium deficiency symptoms appeared in the second crop on the Guelph and Fox soils, in the fifth crop on the Percy, Burford and Otonabee soils, in the sixth crop on the Dundonald and Honeywood soils and in the seventh crop on the Vineland soil. In almost every case noticeable drops in yield coincided with the appearance of visual signs of potassium starvation.

Relationship Between Exchangeable Potassium and Potassium-Supplying Power

In unfertilized soils that have not been intensively cropped the exchangeable potassium level should be at or near the equilibrium level for that soil. Moreover the equilibrium value should be closely related to the potassium-supplying power of the soil. In this study the coefficient of correlation of initial exchangeable potassium and amount of non-exchangeable potassium released during cropping, the Dumfries and Brighton soils excluded, was 0.90^{++}. When the fertilized Dumfries and Brighton soils were included, the correlation coefficient was only 0.53^{+}. The exchangeable potassium level, therefore, is an adequate measure of potassium-supplying power only when it is more or less at equilibrium, i.e., neither augmented by heavy fertilization nor depleted by intensive cropping previous to sampling.

DISCUSSION

The data presented here corroborate much of the data in the literature in regard to the significance of exchangeable and non-exchangeable potassium in relation to crop uptake of potassium. For soils that are more or less at equilibrium, the level of exchangeable potassium may be a reliable indication of potassium-supplying power; in recently fertilized soils there was no relationship between exchangeable potassium and potassium-supplying power.

Although there was an over-all highly significant correlation between exchangeable potassium content and crop yield, the relationship was in error when applied to specific soils. The Honeywood silt loam and the Harriston loam, for instance, contained approximately 195 lb. of exchangeable K per acre, but the Honeywood soil produced 17.0 tons of dry matter per acre while the Harriston produced only 13.5 tons, in the eight crops of alfalfa. The yield difference was probably due in part to the higher potassium-supplying power of the Honeywood soil as shown in Table 2.

It is evident from Figure 1 and the data in Table 1 that some of the soils reached a minimum level of exchangeable potassium after five or six crops. Subsequent crops caused no further decrease in exchangeable potassium level. The Fox soil was apparently at its minimum level even before cropping and no further reduction occurred. This characteristic of intensively cropped soils to retain a minimum level, typical for each soil, of unavailable exchangeable potassium against absorption has been

observed by several workers (1, 2, 4, 9,). The high potassium soils probably were not cropped sufficiently to reach their minimum levels of exchangeable potassium. The variation in level of exchangeable potassium among the soils at the end of the cropping period is a reflection of their relative potassium-supplying powers. The coefficient of correlation of the level of exchangeable potassium at the end of the cropping period and release of non-exchangeable potassium during the cropping period was 0.81^{++} when all 18 soils were considered. When Dumfries and Brighton were omitted $r = 0.87^{++}$.

In regard to potassium nutrition in soil, there are two factors to consider: (*a*) the intensity of potassium in the soil, i.e., the exchangeable potassium level which determines the concentration of potassium in the soil solution,

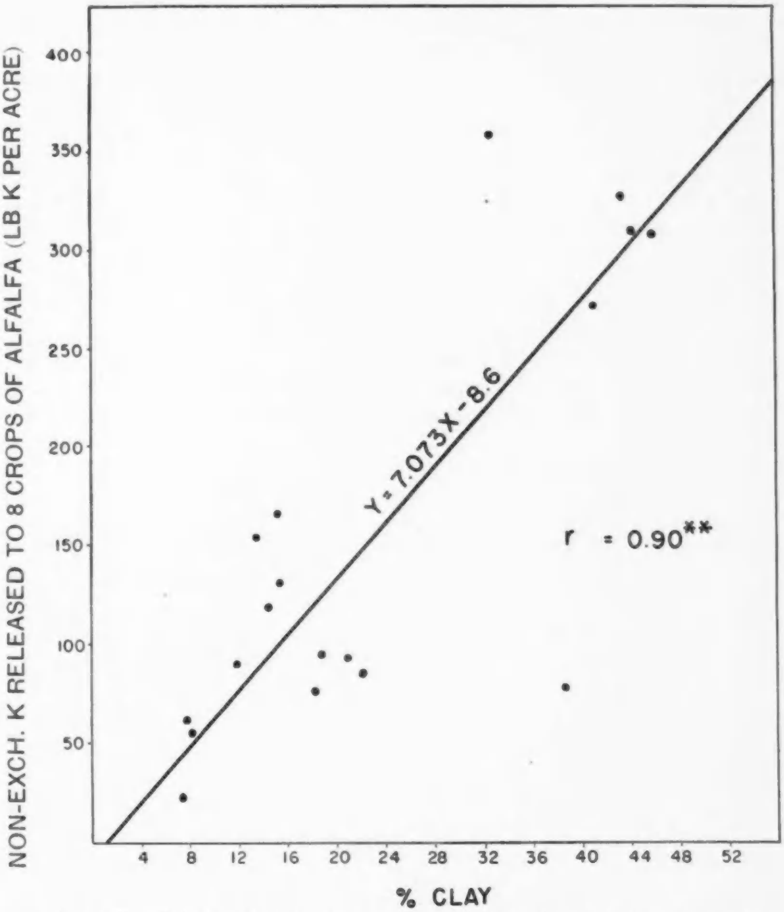

FIGURE 3. Relationship between per cent clay and release of non-exchangeable potassium.

and (*b*) the potassium-supplying power, i.e., the amount and rate of release of non-exchangeable potassium. Although there is a minimum intensity of potassium below which plants will not grow, an excessively high intensity promotes luxury consumption of potassium without corresponding increases in yields. Both intensity and supplying power are important in estimating the potassium fertilizer requirements of soils.

Although it is difficult to relate greenhouse results to field results, numerous studies have shown that response of alfalfa to potassium fertilizer in the field is much less on fine textured soils than on coarse textured soils. The results from this greenhouse study also show that the fine textured soils produced higher yields, released more non-exchangeable potassium and maintained a higher level of exchangeable potassium.

Reitemeier (7) has pointed out that hydrous mica clay minerals are the important carriers of soil potassium. He concluded that the release of potassium from the clay mineral fraction depends on potassium content and amount of hydrous micas in the soil. In the present study a high degree of correlation existed between the clay content of the 18 soils and the amounts of non-exchangeable potassium released to the crops of alfalfa ($r = 0.90^{++}$). The regression line illustrating this relationship is shown in Figure 3. McLean *et al.* (7) found a similar close relationship between clay content and non-exchangeable potassium extracted by 1N HNO_3 from a group of Eastern Ontario soils. Because clay content is a most important factor, it may be possible to determine a value for potassium-supplying power that could be applied to soils within defined ranges in clay percentage. Such values would be useful in conjunction with the measured exchangeable potassium content for predicting potassium fertilizer requirements.

The continuous cropping technique as used in this study is time-consuming and practically precludes the possibility of including a sufficient number of soils to establish reasonably precise values for potassium-supplying power. A laboratory technique properly correlated with the continuous cropping procedure is required. Such a technique has been developed and will be described in a subsequent paper.

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RELATION OF ELEVATION OF A MOUNTAIN STREAM TO REACTION AND SALT CONTENT OF WATER AND SOIL[1]

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ABSTRACT

Water samples were obtained from a number of mountain lakes and irrigation reservoirs in the Okanagan Valley, and from streams emptying them. It was found that in any one drainage basin, the water had a higher pH and salt content at low elevation than at high elevation.

A more dtailed investigation was conducted in the Mission Creek watershed. With decreasing elevation the following relationships were found: (*a*) increasing pH, electrical conductivity, and contents of calcium, potassium and sodium in the stream water; (*b*) increasing pH and conductivity in seepage water; (*c*) increasing pH and conductivity in the soil. Relationships between elevation and pH were similar with stream water, seepage water and soil, as also were relationships between elevation and conductivity values.

INTRODUCTION

In the Okanagan Valley and other parts of the southern interior of British Columbia, most mountain streams have their sources at comparatively high elevations, and empty into lakes or rivers at much lower elevations. Where water is used for irrigation purposes it is usually taken from the stream well down the mountain-side. Precipitation is higher at the greater elevations and temperatures are lower.

The salt content and pH of stream water are important in that they influence the suitability of this water for irrigation purposes. The various salts in solution also determine the fertility value of the water. In the Okanagan Valley, almost all of the irrigation water is obtained either directly or indirectly from mountain streams. It was considered desirable, therefore, to study some of the major factors influencing the pH and salt content of mountain streams.

The first factor studied has been stream elevation. This report deals with an investigation into the changes that occur in pH and salt content of stream water as the stream proceeds down a mountain, and the relationships between the pH and salt content of the stream water and the pH and salt content of near-by soil.

PROCEDURE

Preliminary Work

During the past 15 years, routine chemical analyses have been made on a large number of samples of water obtained from irrigation systems and their water sources in the southern interior of British Columbia. Included in these sources have been streams, lakes and reservoirs at various elevations above sea level. Electrical conductivity and pH determinations were made on these samples.

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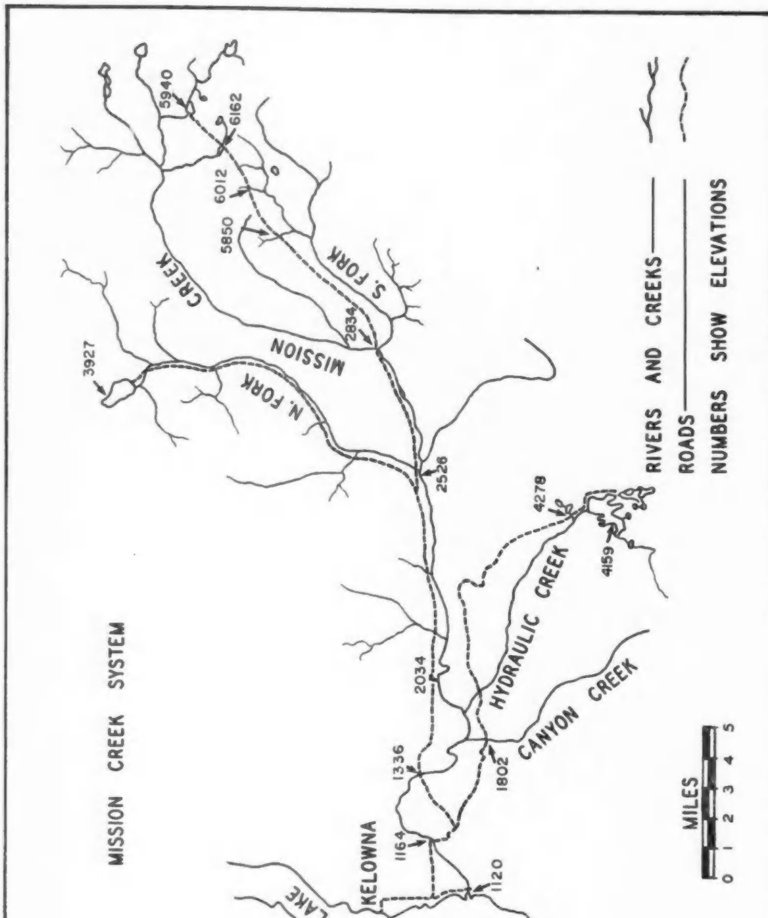

FIGURE 1. Map of Mission Creek and tributaries, showing elevations above sea level.

Mission Creek Investigation

A map of Mission Creek is shown in Figure 1. It is the largest river emptying into Okanagan Lake. It rises in sub-alpine country at about 6300-feet elevation, flows down through heavily wooded coniferous forest, thence through semi-arid ponderosa pine and bunchgrass country, and finally through a wide delta which, until recently, was heavily wooded with cottonwood and similar trees. Annual precipitation at the top has not been measured, but probably ranges around 35 inches. At 4100 feet it averages around 27 inches and at Okanagan Lake about 12 inches.

In August 1949, samples of water were collected at 24 points in the Mission Creek watershed, and were tested for pH, total salt content, and contents of sodium, potassium and calcium. Total salt content was recorded in terms of electrical conductivity (mhos $\times 10^5$) at 25° C. (4). In August 1955, 15 water samples were obtained from springs and seepage outlets and were tested for pH and conductivity. At elevations above 1600 feet the seepage water resulted from precipitation only; at elevations below this, it appeared to be provided largely by irrigation.

In order to determine whether a relationship existed between the soil and the water with regard to pH and conductivity, soil profiles were sampled at nine locations varying widely in elevation, as indicated in Table 1. No attempt was made to study the profiles in detail. At locations 1 to 5, no previous soil survey had been made, and the soil groups indicated in Table 2 are based on preliminary observation only. At locations 6 to 9, the soil groups shown are those previously outlined by

TABLE 1.—SOIL PROFILES SAMPLED

Location number	Elevation	Representative vegetation	Topographic aspects	Soil group	Soil texture	Depth of sampling
	feet					in.
1	6180	Bunch grass meadow Pinus latifolia Abies lasiocarpa	Gently undulating	Intrazonal meadow	Sandy loam	31
2	5445	Abies lasiocarpa Picea Engelmanni Pinus latifolia Pachystima myrsinites	South slope	Brown podzolic	Sandy loam	36
3	5095	Picea Engelmanni Pinus latifolia Pachystima myrsinites	Steep southwest slope	Podzolized grey wooded	Loam	18
4	3780	Pinus latifolia Pseudotsuga taxifolia Larix occidentalis	Steep southwest slope	Grey wooded	Sandy loam	30
5	2575	Pseudotsuga taxifolia	Gentle southwest slope	Brown wooded	Fine sandy	36
6	1760	Pinus ponderosa Bunch grasses	Southwest slope	Dark brown	Sandy loam	22
7	1465	Bunch grasses Pinus ponderosa	West slope	Dark brown	Clay loam	30
8	1180	Populus trichocarpa Betula occidentalis Salix sp. (Now in hay)	Nearly level	Ground-water	Silt loam	18
9	1141	Deciduous trees as above (Now in pasture)	Nearly level	Ground-water	Sandy loam	30

TABLE 2.—RELATION OF ELEVATION TO pH AND SALT CONTENT OF WATER IN REPRESENTATIVE DRAINAGE BASINS

Creek system	Source of water	Elevation in feet	pH	Conductivity*
Ellis Creek	Dam 1	5050	6.79	4
	Dam 4	4320	6.50	3
	Ellis Creek	1536	7.05	5
Penticton Creek	Dam 1	5220	6.30	2
	Dam 2	5120	6.62	2
	Penticton Creek	1530	7.60	5
Trout Creek	Thirsk Dam	3300	7.03	8
	Trout Creek	2775	7.36	9
	Trout Creek	2200	7.32	10
	Trout Creek	1180	7.35	13
Mission Creek	Greystoke Lake	5935	6.71	2
	Belgo Dam	3922	6.79	4
	Mission Creek	2029	7.23	5
	Mission Creek	1331	8.12	17
	Mission Creek	1159	8.31	25
Jones Creek	Aberdeen Lake	4189	6.65	4
	Haddo Lake	4129	6.70	4
	Jones Creek	2200	7.48	9
Coldstream Creek	King Edward Lake	4450	6.68	6
	Coldstream Creek	1700	7.95	10

* Electrical conductivity in mhos x 10^5 at 25° C.

Kelley and Spillsbury (2). The delta soils (8 and 9) were underlaid by a relatively high and variable water table. Soil samples were obtained in the A, B and C horizons from each of the nine profiles. Conductivity values were determined on saturation extracts (3), and pH values on the soil at the "pasty" point (1). For correlation with elevation, the values obtained from each profile were averaged.

RESULTS

Preliminary Data

An examination of the routine records on pH and conductivity of water revealed that almost invariably the water at a higher elevation had a lower pH and a lower salt content than did water in the same drainage basin at a lower elevation. This is illustrated by representative data in Table 2. All streams listed here flow into Okanagan Lake (elevation 1120 feet) or nearby lakes with similar elevation. It will be noted that there were distinct differences between creeks, especially at the lower elevations.

Mission Creek Water Samples

Charts indicating the relationships between elevation, pH and conductivity of stream water samples are shown in Figures 2 and 3. Water sample data included in these charts are those from Mission Creek and its tributaries and from lakes and reservoirs in the Mission Creek system. It

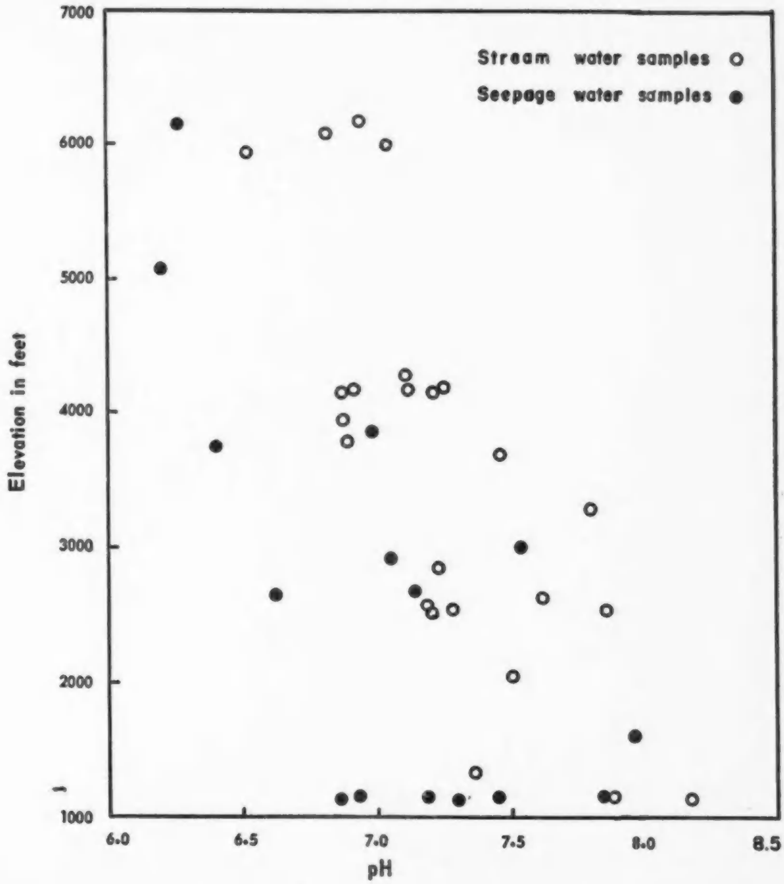

FIGURE 2. Scatter diagram of elevation above sea level and pH values of water.

will be noted that there were strong negative correlations between elevation and pH, and between elevation and conductivity. The wide diversion of some of the points on each chart away from the general line of trend indicates that other factors beside elevation were affecting the pH and conductivity values. The following correlations were obtained on 24 samples of water:

Between pH and elevation	-0.74 ($P = <0.01$),
Between conductivity and elevation	-0.50 ($P = <0.05$),
Between pH and conductivity	$+0.73$ ($P = <0.01$).

Of the ions constituting the total salt content of the water, calcium, sodium and potassium were determined, and these on the 1949 samples only. As an illustration of the trends obtained, sodium is charted against

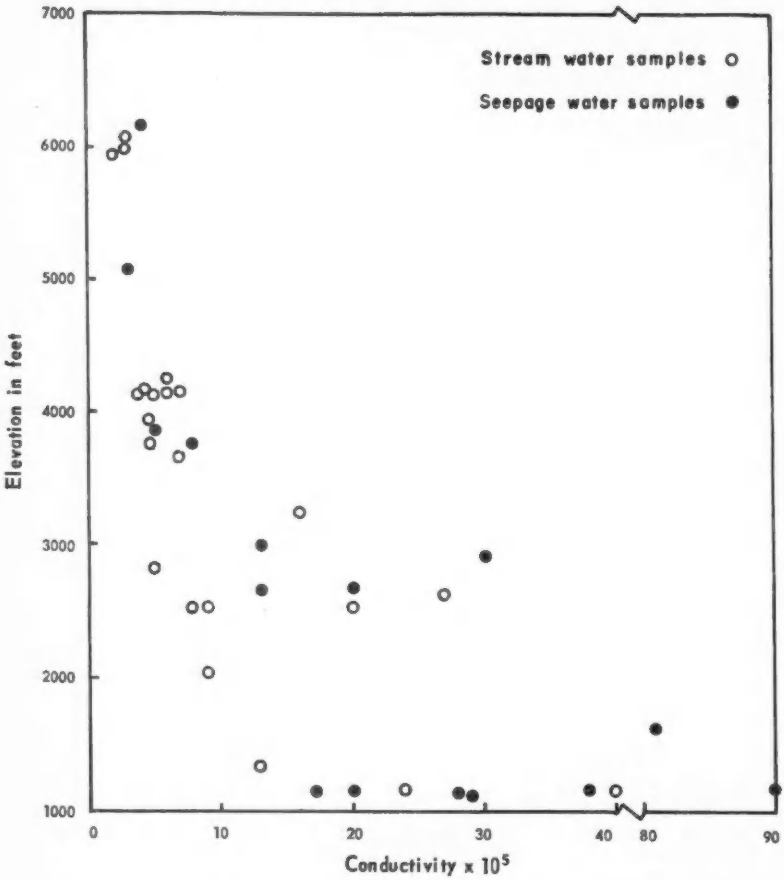

FIGURE 3. Scatter diagram of elevation above sea level and conductivity values of water.

elevation in Figure 4. Trends were similar for calcium and potassium, except that the calcium values were generally higher and the potassium values generally lower than the sodium values.

Seepage Water Samples

The relation of elevation to pH and conductivity of seepage water samples is shown in Figures 2 and 3. These charts indicate relationships between elevation on the one hand and pH and conductivity on the other hand that are quite similar to those for stream water. The following correlations were obtained from 15 samples:

Between pH and elevation	-0.73 ($p = <0.01$),
Between conductivity and elevation	-0.79 ($p = <0.01$).

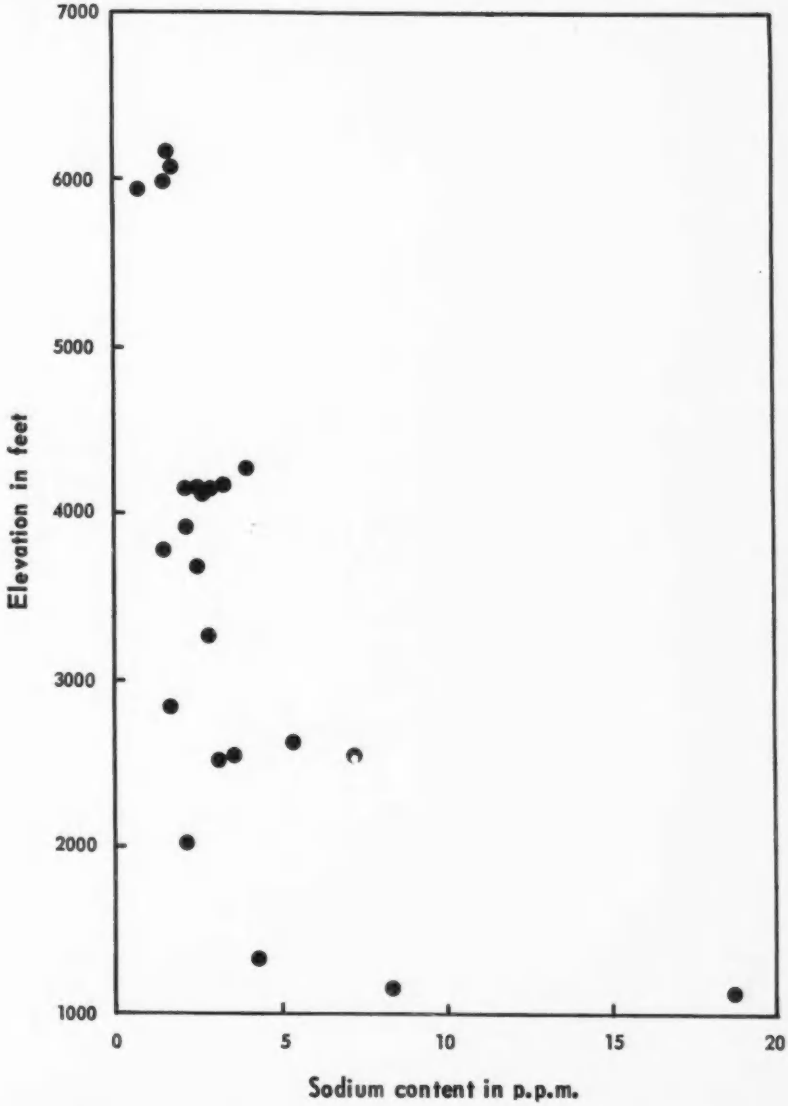

FIGURE 4. Scatter diagram of elevation above sea level and sodium content of stream water.

Soil Profile Samples

The relation of elevation to the average pH and conductivity values for the A, B and C horizons is shown in Figures 5 and 6. The general trends are the same as with the stream water samples and the seepage water

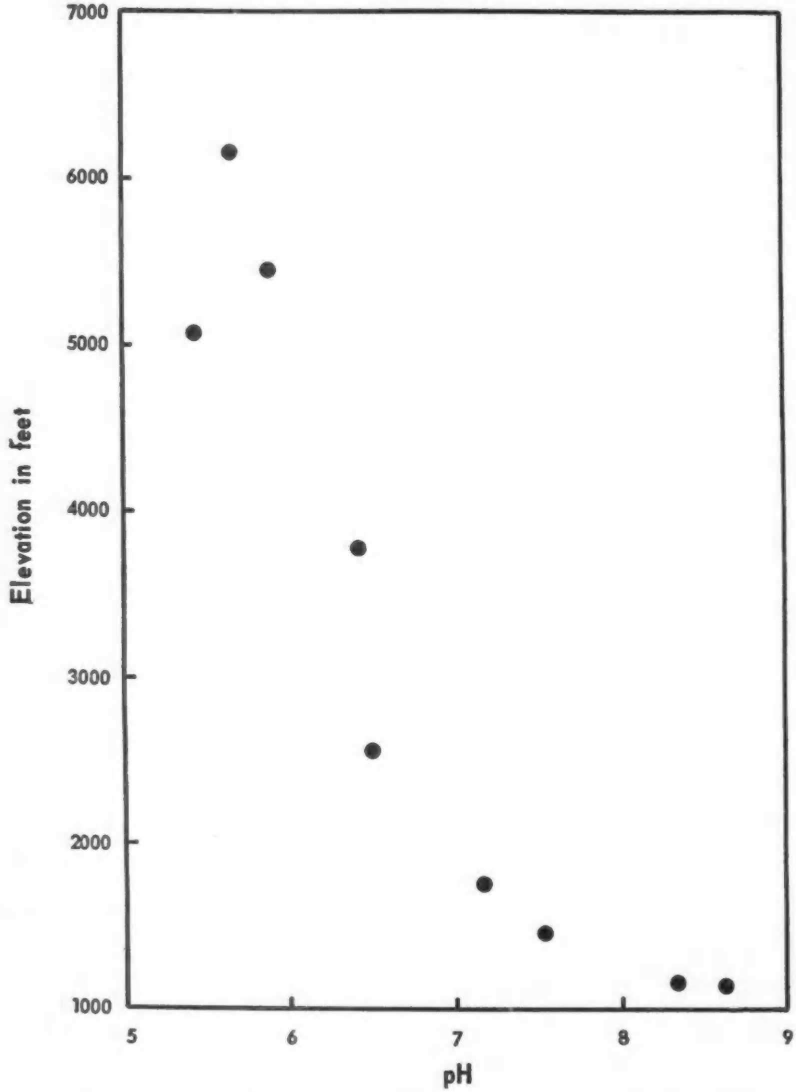

FIGURE 5. Scatter diagram of elevation above sea level and pH values of soil.

samples, although the pH values were lower at higher elevations and higher at lower elevations than with the water. Calcareous soil was found in the B and C horizons below an elevation of 2000 feet. Two of the delta profiles were calcareous in all horizons. Two of the profiles at lower levels showed

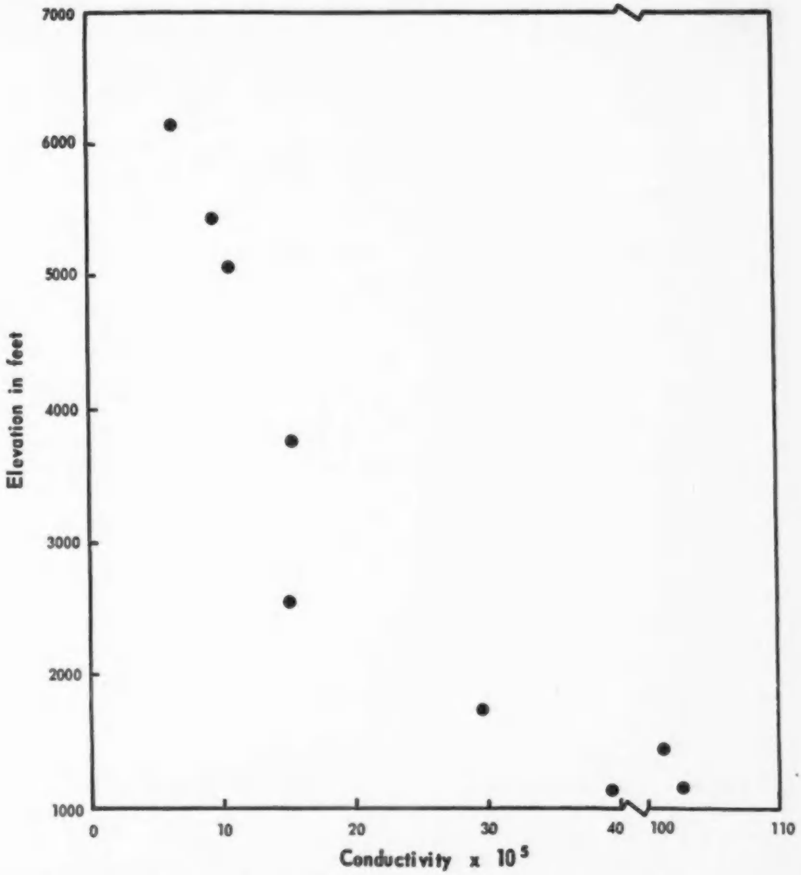

FIGURE 6. Scatter diagram of elevation above sea level and conductivity values of soil.

high salinity due to concentration of salts from seepage water. The following correlations were obtained from the nine profiles:

Between pH and elevation	-0.90 ($p = <0.01$),
Between conductivity and elevation	-0.91 ($p = <0.01$),
Between pH and conductivity	$+0.97$ ($p = <0.01$).

CONCLUSIONS AND DISCUSSION

The evidence submitted in this paper established the fact that the water in mountain streams in the Okanagan Valley tends to become more alkaline and more saline as these streams progress from high elevations to lower elevations. It has also been determined in one watershed (Mission Creek) that the soil itself has, in general, a higher pH and a higher salt content with decreasing elevation from 6180 feet to 1140 feet.

The question arises as to just what causes the increase in pH and salt content of the water as it comes down the mountain. A partial explanation

appears to be indicated by the soils data. In addition, observational evidence suggests certain possibilities. Based both on the results of this investigation and on observational evidence, the following suggestions are offered as causes for the increase in pH and salt content of the water at lower elevations:

1. At high elevations, a larger proportion of the water enters the stream bed and the reservoirs by surface flow than is the case at low elevations. This is largely due to heavier precipitation and lower transpiration at the higher elevations. There is more snow to melt, rainfall is heavier, and the soil is usually wetter and absorbs the water more slowly. Hence, at higher elevations a lower proportion of the water percolates into the soil and subsequently enters the stream bed as seepage water. Surface water has, of course, less opportunity to pick up salts than has seepage water.

2. Owing to heavier precipitation and lower transpiration at high elevations, the soil is leached more fully than at lower elevations; hence it contains a lower content of soluble salts. Water seeping through the soil at the top of the mountain, therefore, will pick up smaller amounts of salts than will the same volume of water at the foot of the mountain.

Both of these factors are associated with climatic variations, that are in turn caused largely by elevation. In other words, the effects of elevation are indirect. The combined effect of these two factors causes the water entering the stream to consist more and more of seepage water, which contains an increasing content of salts, as the stream progresses down the mountain. Where the stream bed is steep and the stream is short (as with Penticton Creek, Table 2) the effect on water pH and conductivity is much less pronounced than where the stream is longer and empties a larger watershed (as with Mission Creek).

3. There is a distinct possibility that the amount of salts picked up by seepage water may be affected by the underlying rock formation. Different types of rocks yield different types and amounts of soluble salts as they disintegrate. This possibility has not been investigated.

The relative amount of flow in a stream can affect markedly the rate of change in pH and salt content with decreasing elevation. It has been found that in any one stream, the greater the flow of water the lower are the pH and salt content at the mouth of the stream. Thus in the "flood" season when the silt content is high, pH and salt content are low. This appears to be due to a much higher proportion of the water entering the stream as surface water at that time than during the rest of the year. A flood condition is usually caused by heavy rains. Data on this factor will be reported more fully elsewhere.

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A PERCOLATION METHOD FOR MEASURING POTASSIUM-SUPPLYING POWER OF SOILS[1]

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ABSTRACT

An apparatus for continuous circulation of water through a soil sample and a cation exchange resin has been devised by modification of the Lees perfusion apparatus. The amount of exchangeable and non-exchangeable potassium released from the soil and adsorbed by the resin was found to correlate highly with the amount of potassium taken up by alfalfa grown continuously in the greenhouse ($r = 0.91$). The rate and amount of release differed for different soils and the rate of release showed little correlation with the original level of exchangeable potassium. It is suggested that the rate of release, i.e., potassium-supplying power, is a soil type characteristic and not a function of management or fertilization. The percolation method proposed will permit ready evaluation of the potassium-supplying power of Ontario soils.

Many soils are known to release large amount of non-exchangeable potassium upon continuous cropping. Indeed, the amount of exchangeable potassium in many soils has been found to remain virtually constant despite the annual crop removal of potassium in amounts that may well exceed the exchangeable potassium content of the soil as determined by extraction of the soil with neutral normal ammonium acetate solution. Still in other soils, the exchangeable potassium content may be readily depleted to the level at which plants must depend on the release of non-exchangeable potassium for their growth.

It has been reported by many workers (1, 6, 7) that soils vary greatly in their capability to supply potassium under continuous cropping in the greenhouse. In the laboratory, extraction with strong acid (2), or electrodialysis (6) has given results that correlate with potassium-supplying power determined by continuous cropping in the greenhouse. In soils of low supplying power, however, strong acids may extract appreciable quantities of non-exchangeable potassium from soils which yield negligible amounts to plants.

In an attempt to correlate the potassium-supplying power of soils as determined by continuous cropping with the rate of release of non-exchangeable potassium upon successive extractions of the soil with different salt solutions, Merwin and Peech (5) showed that 0.5 N acetate solutions of different cations gave widely divergent results. In general, the amounts of potassium extracted by monovalent cations were greater than those extracted by bivalent cations.

Matthews (4) showed that the amount of potassium extracted by NH_4^+ alone was less than the total amount extracted by the calcium ion followed by NH_4^+ even though the total volume of solution leached through the soil was the same in both instances. He also found that dilute solutions, 0.005 N, extracted as much potassium from soil as more concentrated

[1] Contribution from Department of Soils, Ontario Agricultural College, presented at Annual Meeting, Canadian Society of Soil Science, Toronto, June 1956. (The percolation procedure was first outlined by the senior author in a doctorate thesis prepared under the direction of M. Peech and submitted to the Graduate School, Cornell University, September, 1952).

[2] Professor of Soils, and Lecturer, respectively, Ontario Agricultural College, Guelph, Ontario.

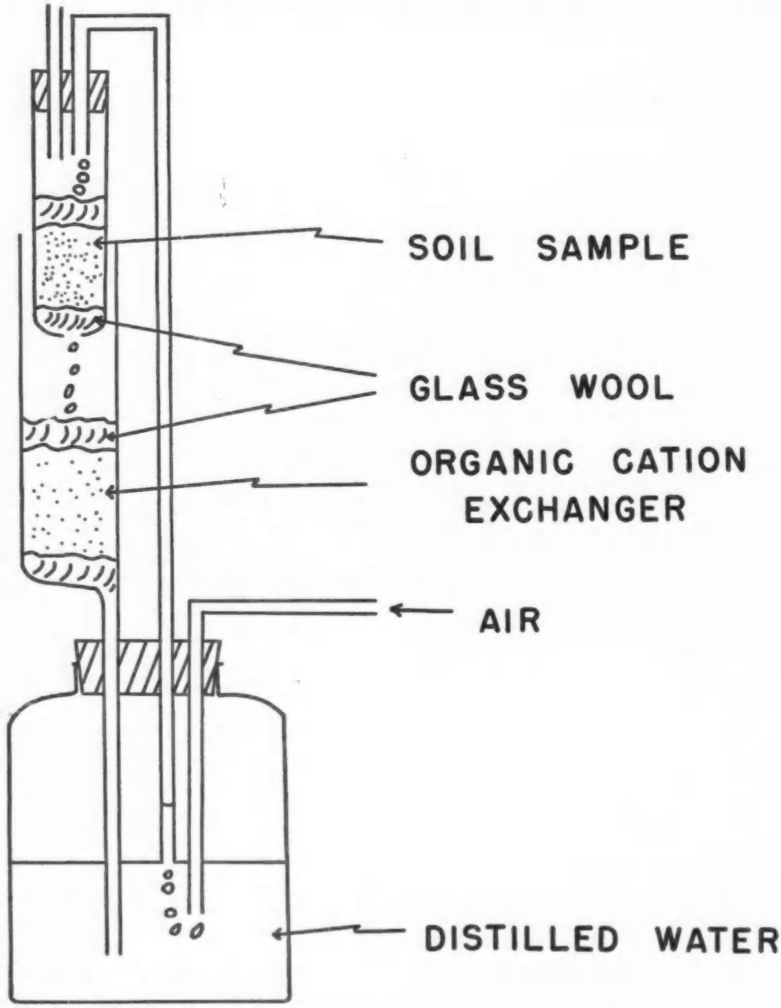

FIGURE 1. Percolation apparatus for measuring potassium-supplying power of soils.

solutions although more solution was required. It was concluded that extraction of soils with dilute solutions should provide the best measure of the relative potassium-supplying power of soils. At any rate, dilute solutions should simulate the action of the soil solution to a greater extent than more concentrated solutions.

Williams and Jenny (8) reported a large release of potassium by the Romona soil upon prolonged extraction with CO_2—saturated water at pH 4.01. They found that 10 litres of water leached through the soil over

a period of 19 days extracted appreciably more potassium than the amount determined to be exchangeable initially by neutral, normal ammonium acetate solution. Moreover, they concluded that volume of extractant rather than time of percolation determined the amount of potassium extracted from a particular soil.

In the present paper the percolation method for measuring potassium-supplying power is described and results obtained with a number of soils are given.

DESCRIPTION OF PERCOLATION METHOD

The method, which utilizes the modified apparatus of Lees (3), as shown in Figure 1, is designed to use dilute extracting solutions and to reduce the total amount of extractant required. The cation exchange resin must be of the sulphonic acid type in order to avoid hydrolysis of the potassium-resin. Hydrogen amberlite IR-100 and IR-120 were found to be satisfactory.

Ten grams of air-dry soil were mixed with sufficient acid-washed sand to permit adequate percolation of water through the mixture. Distilled water (approximately 500 ml.) was placed in the reservoir bottle and compressed air was introduced into the system to force the water up to the top of the tube containing the soil-sand mixture. The water percolated downward through the soil and then through the column of cation exchange resin, which adsorbed the cations contained in the water. The rate of percolation of the solution was about 5 litres per day. Periodically the resin containing potassium (and other exchangeable metal ions) was

TABLE 1.—AMOUNTS OF POTASSIUM RELEASED BY 18 ONTARIO SOILS DURING CONTINUOUS PERCOLATION AND CONTINUOUS CROPPING WITH ALFALFA IN THE GREENHOUSE

Soil type	Continuous percolation. Cumulative amounts of K^+ removed after				Continuous cropping total K^+ in 8 crops and roots
	17 hours	42 hours	65 hours	100 hours	
	lb./ac.	lb./ac.	lb./ac.	lb./ac.	lb./ac.
Haldimand clay loam	387	675	811	965	611
Brookston clay	376	586	761	827	442
Saugeen silty clay	164	326	428	576	520
Huron clay	147	290	415	548	404
Schomberg silty clay	208	327	440	549	352
Bondhead loam	230	389	432	566	313
Vineland loam	98	148	184	232	187
Honeywood silt loam	225	266	319	378	273
Dundonald loam	174	248	314	379	197
Otonabee loam	165	254	314	384	146
Harriston loam	167	231	300	378	200
Percy loam	151	198	237	278	151
Dumfries sandy loam	592	735	840	967	462
Burford loam	135	232	297	356	130
Guelph loam	86	120	147	206	93
Pontypool loamy sand	178	234	268	310	148
Brighton loamy sand	437	473	498	527	305
Fox sand	75	101	128	147	31

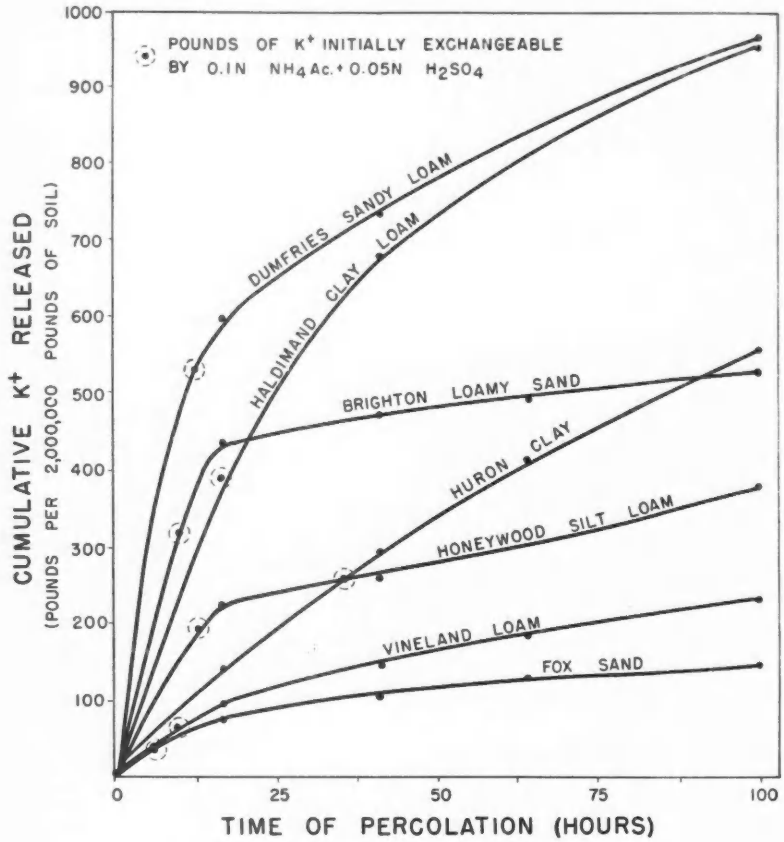

FIGURE 2. Release of potassium during continuous percolation.

replaced and leached with about 500 ml. of 0.5 N hydrochloric acid to remove the adsorbed metal ions and to regenerate the exchanger to be used again in the percolation apparatus. The exchangeable potassium contents of the soils initially and after 100 hours' percolation were determined by extraction with 0.1 N ammonium acetate and 0.05 N sulphuric acid with a 1 : 10 soil: solution ratio for 15 minutes. Potassium in the soil extracts and in the resin extracts was measured with a Baird flame photometer.

The percolation procedure was carried out on samples of the 18 soils used in a continuous cropping experiment reported in a previous paper (7).

RESULTS

At the end of the 100-hour extraction period, the pH of the percolating liquid, which depends on the original electrolyte content of the soil, was

between 3.3 and 3.5. It was unlikely, therefore, that the acidity of the extractant resulted in excessive decomposition of the potassium-bearing minerals. The exchange resin effectively removed the metal ions from the solutions as no measurable quantities of potassium were found in the percolating liquid at any time. Indeed, the liquid passing through the soil was essentially weakly acidified water.

The cumulative amounts of potassium extracted by the percolation procedure, shown in Table 1, illustrate wide differences in the potassium-supplying power of the soils. The data for some of the soils are shown in Figure 2. At the end of the 17-hour percolation period, most of the soils had released an amount of potassium equal to or greater than the amount initially exchangeable by 0.1 N NH_4Ac and 0.05 N H_2SO_4 solution. The level of exchangeable potassium in a soil, however, does not necessarily indicate the potassium-supplying power of the soil. The Brighton soil, as shown in Figure 2, had a high initial exchangeable potassium content due to potassium fertilization; however, when the exchangeable potassium was depleted after 17 hours' percolation, the curve for subsequent percolation was relatively flat indicating a low potassium-supplying power. The Huron clay, however, with a moderate exchangeable potassium content continued to release appreciable amounts of potassium even after the 17 hours of percolation. The continuous cropping study reported previously (7) gave similar relative results.

The total potassium taken up by 8 crops of alfalfa tops and roots was highly correlated with the total potassium released during 100 hours of

TABLE 2.—INITIAL AND FINAL EXCHANGEABLE POTASSIUM CONTENTS AND AMOUNTS OF NON-EXCHANGEABLE POTASSIUM RELEASED BY 18 ONTARIO SOILS UNDER CONTINUOUS CROPPING AND CONTINUOUS PERCOLATION

Soil type	Initial exch. K^+	Percolation for 100 hr.		Cropping for 273 days	
		Non-exch. K^+ released	Final exch. K^+	Non-exch. K^+ released	Final exch. K^+
	lb./ac.	lb./ac.	lb./ac.	lb./ac.	lb./ac.
Haldimand clay loam	390	609	34	359	138
Brookston clay	356	529	58	328	242
Saugeen silty clay	347	276	47	311	138
Huron clay	266	340	58	310	172
Schomberg silty clay	232	374	57	273	153
Bondhead loam	246	378	58	167	100
Vineland loam	68	182	18	155	36
Honeywood silt loam	198	214	34	132	57
Dundonald loam	140	270	31	120	63
Otonabee loam	131	296	43	95	80
Harriston loam	193	217	32	93	86
Percy loam	108	192	22	91	48
Dumfries sandy loam	513	496	42	87	138
Burford loam	112	286	42	79	61
Guelph loam	79	162	35	77	63
Pontypool loamy sand	129	200	19	62	43
Brighton loamy sand	316	225	14	56	67
Fox sand	33	124	10	23	25

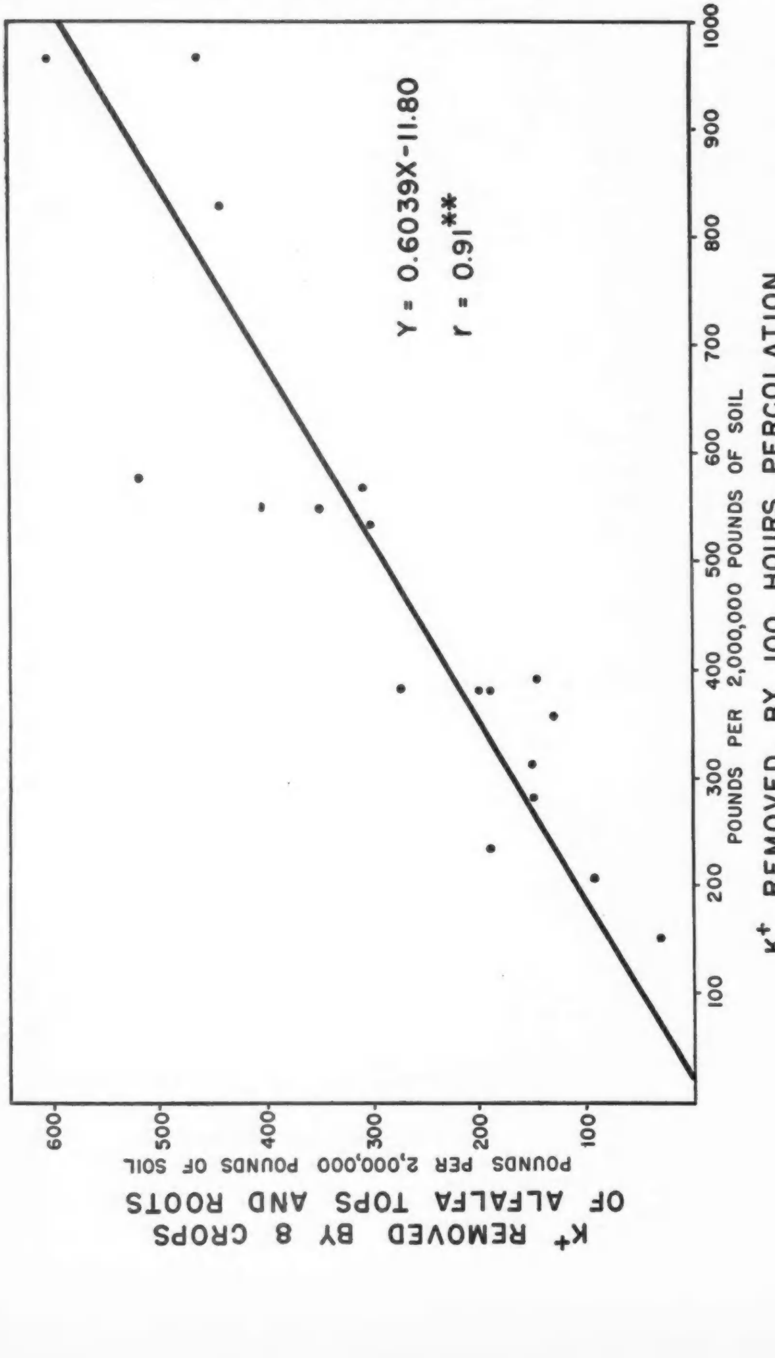

FIGURE 3. Relationship between amounts of potassium removed from soil by percolation procedure and by continuous cropping.

percolation. ($r = 0.91^{++}$)*. The regression line and equation are shown in Figure 3.

The non-exchangeable potassium released during percolation was calculated by subtracting the decrease in exchangeable potassium content of the soil from the total amount of potassium extracted. The coefficient of correlation of the non-exchangeable potassium released by percolation shown in Table 2 and the amount released by cropping was 0.83^{++}.

The exchangeable potassium content of the soils was reduced relatively quickly under percolation to a constant level that seemed to be characteristic of the soil. The minimum levels of exchangeable potassium in the range of 58 to 10 lb. of K per acre after percolation were considerably lower than the minimum levels after 8 crops of alfalfa as shown in Table 2.

It was also found that, at the end of the 17-hour period of percolation, the amount of potassium removed was approximately equal to, and in some instances greater than, the initial exchangeable potassium content. The potassium extracted during subsequent percolation depended on release from non-exchangeable form. The slope of the release curves after the initial 17-hour period should be an index of the potassium-supplying power. The correlation of the amount of non-exchangeable potassium released during cropping with the amount of potassium released during the 17- to 100-hour period of percolation was highly significant ($r = 0.94^{++}$).

DISCUSSION

Any correlation between laboratory and greenhouse or field methods for measuring the potassium-supplying power of soil presupposes that the potassium concentration in the soil solution is sufficiently high to maintain the growth of plants; otherwise the removal of potassium by cropping will be nil. Moreover, the amount of potassium that is actually removed by cropping depends on the number of crops that are grown on the soil; similarly, the relative amounts of potassium removed by the percolation procedure depend on the length of time percolation is continued. The 100-hour percolation period was chosen because by that time most of the soils had reached a more or less constant rate of release of potassium.

The percolation procedure as described here does permit evaluation of relative potassium-supplying powers of this group of soils in the same way as the continuous cropping procedure. The laboratory procedure, however, has some important advantages:

(1) The time required to determine the potassium-supplying power is short compared to the continuous cropping procedure.

(2) The extractant employed is slightly acidified water containing low concentrations of electrolyte and hence it simulates the solvent action of the natural soil solution.

(3) The potassium in the extract is concentrated by means of the cation exchange resin thus permitting its rapid and accurate determination.

(4) The equivalent of a large volume of extractant is obtained by repeated circulation of a small volume through the system.

* Throughout the paper ++ after a correlation coefficient indicates significance at the 1 per cent level.

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FERTILITY STUDIES ON SOME NEW BRUNSWICK SOILS

II. SOIL POTASSIUM SUPPLY AS SHOWN BY GREENHOUSE AND CHEMICAL TESTS[1]

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ABSTRACT

Fertility investigations were conducted on samples of surface soil collected from six farms on each of five soil types occurring in the Saint John River Valley. The effect of applied potassium on the yield and potassium content of ladino clover served as a basis for evaluating several chemical methods used in assessing the potassium status of different soils.

Applied potassium resulted in significant increases in yield on two soils and in the potassium content of the crop on all soils. The higher the potassium content of the crop grown without potassium fertilizer, the lower was the increase in yield from applied potassium.

Soil potassium values, as determined by four chemical methods, varied significantly between soil types. Correlation coefficients relating uptake of potassium by ladino clover with the values obtained by the four methods were significant at the 1 per cent level.

INTRODUCTION

In the fall of 1952, an investigation was initiated to assess the phosphorus and potassium supplies in surface samples of a number of soil types in this province. One of the objectives of the study was to correlate chemical tests for these elements with crop response to applied fertilizer in greenhouse trials. Information on the phosphorus supply of these soils was presented in a recent publication (3). The results pertaining to potassium are discussed in this paper.

MATERIALS AND METHODS

Composite samples of surface soil were collected from six farms on each of five soil types in the fall of 1952. The soils have been described in soil survey reports (6, 7, 8).

The procedure employed in the greenhouse has been outlined (3). Ten pounds of air-dried soil were placed in glazed gallon pots. The fertility treatments consisted of phosphorus, potassium and lime, applied singly and in combination in a $2\times2\times2$ factorial design. In addition to the zero level, phosphorus (P_2O_5) and potassium (K_2O) were each applied at a rate of 200 lb. per acre, and lime in the form of calcium hydroxide was applied as required to raise the soil pH to 6.5 as predetermined by titration curves (2). Ladino clover was used as the indicator crop with four cuts being harvested. The potassium content of the crop, grown with and without potassium fertilizer, was determined on composite samples from three replications. Samples were ground in a Wiley Mill and potassium was determined with a Beckman DU spectrophotometer and flame attachment as proposed by DeLong *et al.* (1).

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Estimates of soil potassium were made by extracting with the following: (a) water, utilizing a 1:10 soil to extractant ratio and shaking for 30 minutes; (b) sodium acetate, at pH 4.85, as proposed by Peech and English (4); (c) normal neutral ammonium acetate (9), and (d) boiling nitric acid solution (5). Potassium in the extracts was determined with the flame photometer.

RESULTS AND DISCUSSION

Greenhouse Results

The mean yield, the potassium content of the clover and the amount of potassium removed by the crop grown with and without potassium fertilizer are presented for each soil type in Table 1.

TABLE 1.—YIELD, POTASSIUM CONTENT AND AMOUNT OF POTASSIUM REMOVED BY LADINO CLOVER
(Mean values for 6 farms on each soil type)

Soil type	Yield per pot		Potassium (K) content		Potassium (K) uptake per pot	
	No K** applied	K** applied	No K** applied	K** applied	No K** applied	K** applied
	gm.	gm.	%	%	mgm.	mgm.
Caribou loam	33.5	33.0	1.88	2.64	632.4	854.6
Carleton loam	30.4	30.3	1.60	2.21	480.5	661.4
Interval silt loam	31.0	36.7	1.24	1.94	383.0	691.8
Riverbank sandy loam	32.2	34.7	1.58	2.25	515.7	768.6
Tracy loam	30.6	32.2	1.49	2.19	449.7	697.2
L.S.D. (0.05)*	2.4		——		——	
L.S.D. (0.01)*	3.3		0.19		63.4	

* Based on pooled (treatment × farms) interaction within each soil type.
** No K treatment included check, P, lime, and lime +P.
K treatment included K, P + K, lime + K, and lime + P + K.

The results show that, under greenhouse conditions, potassium fertilizer has given a significant increase in yield on the two water-worked soil types, namely, Interval silt loam and Riverbank sandy loam. Potassium fertilizer resulted in significant increases in the potassium content of the crop and in the uptake of potassium by the crop, on all soil types. On the basis of the 30 soils, the higher the potassium content of the crop grown without potassium fertilizer, the lower was the increase in yield from an application of this element (Figure 1). The correlation coefficient expressing this relationship (−0.730) was significant at the 1 per cent level. These data suggest that plant analysis may be of value in assessing the potassium status of different soils.

The analyses of variance in Table 2 show that the variations in yield and in uptake of potassium by the crop between soil types and between farms within the same soil type were each significant at the 1 per cent

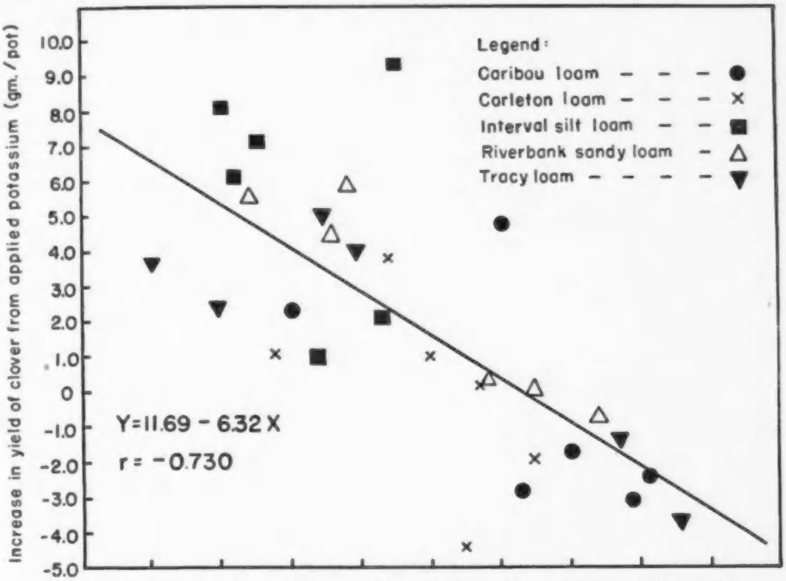

FIGURE 1. Relationship between potassium content of ladino clover and yield increase from applied potassium

level. The effects of applied potassium on yield and on uptake of potassium were also highly significant. The interactions of potassium on soil types were significant at the 1 per cent level; that is, the effects of applied potassium on yield and on uptake of potassium were greater on some soil types than on others.

TABLE 2.—ANALYSES OF VARIANCE OF DATA RELATING TO YIELD AND POTASSIUM UPTAKE BY LADINO CLOVER

Source of variation	D.F.	Yield		Potassium (K) uptake	
		M.S.	F.	M.S.	F.
Soil type	4	332.21	5.79**	323,113.00	44.48**
Farms within soil type	25	633.69	11.05**	219,691.07	30.24**
Potassium	1	633.00	11.04**	3,527,211.09	485.54**
Potassium X soil type	4	216.45	3.77**	26,192.95	3.61**
Treatment X farms (error)	175	57.35		7,264.46	

** Significant at 0.01.

SOIL POTASSIUM EXTRACTED BY VARIOUS CHEMICAL METHODS

The mean values for potassium extracted from the soil by four chemical methods are presented in Table 3. The variations in the potassium values for the different soil types exceeded the corresponding variations between farms on the same soil type in all instances.

TABLE 3.—SOIL POTASSIUM VALUES AS DETERMINED BY VARIOUS CHEMICAL METHODS

(Mean values for 6 farms on each soil type)

Soil type	Water soluble K	Sodium acetate soluble K	Exchangeable K	Nitric acid soluble K
	me./100 gm.	me./100 gm.	me./100 gm.	me./100 gm.
Caribou loam	0.049	0.26	0.45	0.64
Carleton loam	0.035	0.16	0.30	0.60
Interval silt loam	0.022	0.08	0.16	0.39
Riverbank sandy loam	0.034	0.16	0.28	0.34
Tracy loam	0.028	0.13	0.22	0.47
M.S. between soil type	0.00059	0.0282	0.0690	0.0985
M.S. between farms within soil type	0.00016	0.0067	0.0119	0.0292
F value	3.69*	4.21**	5.80**	3.37*

* Significant at 0.05.
** Significant at 0.01.

The amounts of water-soluble, sodium acetate soluble, exchangeable and nitric acid soluble potassium were significantly correlated at the 1 per cent level. The correlation coefficients relating the values for water-soluble with the values for sodium acetate soluble, exchangeable and nitric acid soluble potassium were +0.934, +0.925 and +0.754 respectively. The correlation coefficients expressing the relationship between sodium acetate soluble and the exchangeable and nitric acid soluble forms were +0.976 and +0.807 respectively. A similar comparison of exchangeable and nitric acid soluble potassium showed a correlation coefficient of +0.800.

RELATIONSHIP BETWEEN SOIL POTASSIUM VALUES AND CROP RESPONSE IN THE GREENHOUSE

In the evaluation of chemical methods a number of criteria might be employed as measurements of crop performance. In this instance, total potassium uptake by the crop was used as it embraced both yield and potassium content of the crop. The uptake of the element by the crop on pots receiving no potassium was expressed as a percentage of the uptake on those receiving potassium. The correlation coefficients relating soil potassium values and the effect of applied potassium on potassium uptake are presented in Table 4. When the correlation coefficients were calcu-

TABLE 4.—RELATIONSHIP BETWEEN SOIL POTASSIUM VALUES AND POTASSIUM UPTAKE BY LADINO CLOVER

(Uptake on no K treatment expressed as percentage of uptake on K treatment)

Soil type	D.F.	Water soluble K	Sodium acetate soluble K	Exchangeable K	Nitric acid soluble K
Caribou loam	4	+0.722	+0.892*	+0.923**	+0.917**
Carleton loam	4	+0.677	+0.814*	+0.819*	+0.773
Interval silt loam	4	+0.898*	+0.312	+0.409	+0.349
Riverbank sandy loam	4	+0.662	+0.870*	+0.862*	+0.898*
Tracy loam	4	+0.905*	+0.980**	+0.930**	+0.641
All soils	28	+0.704**	+0.744**	+0.696**	+0.695**

* Significant at 0.05.
** Significant at 0.01.

lated without regard to soil type, the results obtained by all methods were remarkably similar and were significant at the 1 per cent level. The regression equations relating response to applied potassium and soil potassium values are as follows: water-soluble, $Y = 766.5X + 39.1$; sodium acetate soluble, $Y = 109.9X + 47.8$; exchangeable, $Y = 72.5X + 44.7$ and nitric acid soluble, $Y = 51.3X + 40.1$. Soil potassium values obtained by the four methods were expressed as percentages of the cation exchange capacities of the 30 soils which ranged from 9.6 to 19.4 me. per 100 gm. Correlation coefficients relating response to applied potassium and degree of potassium saturation for water-soluble (+0.639), sodium acetate soluble (+0.695), exchangeable (+0.643) and nitric acid soluble potassium (+0.676) were significant at the 1 per cent level.

When the data relating soil potassium values and crop response on individual soil types are considered there is evidence that some methods are more satisfactory than others on a particular soil.

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EFFECT OF CROP RESIDUES AND FERTILIZER TREATMENTS ON THE YIELD AND PROTEIN CONTENT OF WHEAT[1]

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ABSTRACT

Results are presented showing the effect of alfalfa, grass and wheat crop residues on the yield and protein content of wheat during the 6-year period, 1948-1953.

The yield of first crop wheat after alfalfa (34.4 bu./ac.) was greater than the yield after grass (25.6 bu.). The yields of wheat after fallow in which wheat straw residues had been incorporated were 31.4 and 32.4 bu. The second wheat crop after alfalfa (23.8 bu.) yielded more than the second crop after grass (19.4 bu.) and also than the second crop after fallow (18.4 and 16.3 bu.)

Returning wheat crop residues reduced yields. This effect was slight the first year after fallow but more pronounced the second year after fallow. The depressing effects of grass and wheat crop residues were partly offset by applications of 16-20-0 at 108 lb. per acre. Yields of the second crop of wheat after fallow were greater where sweet clover had been ploughed down in the fallow year or where the straw residues were burned.

The protein content was highest after alfalfa and where sweet clover was ploughed down in the fallow year. Protein content was low after grass breaking. Fertilizer treatments, although they increased yield, had little effect on protein content.

INTRODUCTION

The return of cereal crop straw to the land has been the recommended practice in Manitoba for many years. Returning these residues is desirable as a means of reducing loss of organic matter and protecting the soil from erosion. However, residues of cereal crops frequently reduce the yield of subsequent grain crops. This yield depression appears to be due to immobilization of nitrogen by soil organisms during decomposition of the residues. A similar problem frequently occurs following the breaking of grass sod.

LITERATURE REVIEW

Russell (8) indicates that where the nitrogen content of a residue is less than 1.2 per cent there is a tendency for soil organisms to immobilize nitrogen while decomposing the residue, whereas release of nitrogen takes place in the early stages of decay where the nitrogen content exceeds 1.8 per cent. With an intermediate nitrogen content there is little effect on the soil mineral nitrogen during early stages of decomposition. The effect of the residue on soil mineral nitrogen is influenced by conditions under which decay takes place. Pinck (7) found that in Maryland a ton of wheat straw immobilized 16 to 18 lb. of nitrogen if decomposing under winter conditions and 21 to 28 lb. during the summer months.

Newton *et al.* (5) studied the effect of alfalfa, brome, timothy and western rye grass on the yield and protein content of succeeding wheat crops. Yields were about the same following each of the four crops studied, but when grasses were down for 2 years or more, the protein content of subsequent wheat crops was depressed as compared to that of wheat following

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alfalfa. The decrease in protein content was most marked following brome grass. Newton *et al.* (4) attributed the higher protein content of wheat following alfalfa to more rapid nitrification of alfalfa residues. Ellis (2) reported that both yield and protein content of wheat were lower following grass than they were following alfalfa.

Mineral nitrogen applications do not usually have a marked effect on the protein content of wheat. McNeal and Davis (3) found that on nitrogen deficient soils, application of nitrogen at rates of 50 and 100 lb. per acre had little effect on protein content although yield increase was obtained. Peterson (6) found that spring applications of nitrogen were more effective than fall applications in increasing the protein content of winter wheat.

OUTLINE OF EXPERIMENT

An experiment to study the effect of crop residues and fertilizer treatments on the yield and quality of wheat was begun in 1943 on the Fertility Field of the University of Manitoba. The soils on this experimental area are clay textured and are members of the Red River and Fort Garry Soil Associations described by Ehrlich *et al.* (1).

For the purpose of this study two rotations were laid out on land which previously had been used to grow cereal grains for many years without fertilizer treatment. The rotations, a grain-hay and a grain-fallow rotation, are listed below and were laid out in a modified split-plot design.

Grain-Hay Rotation		*Grain-Fallow Rotation*	
Year	*Crop*	*Year*	*Crop*
1	Fallow	1	Fallow
2	Seed Hay	2	Wheat
3	Hay, two cuts	3	Wheat
4	Hay, one cut, break and fallow	4	Fallow
5	Wheat, fall plough return stubble only	5	Wheat
6	Wheat	6	Wheat

Plots were arranged in six blocks, one for each year in the grain-hay rotation. This provided for two cycles of the grain-fallow rotation in the 6 years and thus a duplication of all treatments in that rotation. There were eleven systematically arranged 1/20 acre plots in each of the six blocks. The treatments for these eleven plots were:—

(1) A legume—alfalfa
(2) A legume-grass mixture—alfalfa, brome, meadow fescue and timothy
(3) A grass mixture—brome, meadow fescue and timothy
(4) Return stubble only—plough
(5) Return straw and stubble—disk and cultivate
(6) Return straw and stubble—cultivate
(7) Burn straw and stubble—cultivate
(8) Return straw and stubble—sweet clover sown with second wheat crop and ploughed down in fallow year
(9) A legume—alfalfa
(10) A legume-grass mixture—alfalfa, brome, meadow fescue and timothy.
(11) A grass mixture—brome, meadow fescue and timothy.

Plots 9, 10 and 11 were the same as Plots 1, 2 and 3, providing a duplication of treatments in the grain-hay rotation. Wheat crops on all plots in both rotations received fertilizer treatments on 1/80 acre sub-plots as follows:

A. Check—no fertilizer

B. Ammonium phosphate (11-48-0) at 45 lb. per acre drilled in with the seed for both first and second crop wheat

C. Ammonium phosphate (16-20-0) at 108 lb. per acre drilled in with the seed for both first and second crop wheat.

D. Manure at 4 tons per acre applied in the fallow year for first crop and during the winter for the second wheat crop. In 1952 this was increased to 8 tons per acre.

Of these treatments, B is essentially a phosphorus treatment; C supplies both nitrogen and phosphorus, and D is a source of nitrogen, phosphorus and potassium.

The wheat from each 1/80 acre plots was harvested, threshed and weighed, and grain yield calculated in bushels per acre. Samples of the grain were taken and nitrogen was determined on ground, oven-dry samples by the Kjeldahl method. Protein was calculated on the basis of 13.5 per cent moisture.

Analysis of variance was run on the yield and protein data. Although the arrangement of main plot treatments was systematic, each treatment was at two separate locations, not in line. The data obtained from these duplicated plots were averaged and consequently each treatment could logically be considered random in any one year. Replication was obtained by using data collected for 6 years, by which time both rotations had completed one cycle around the six blocks in the experiment.

RESULTS AND DISCUSSIONS

Yield Data

Mean yields of wheat for the six-year period 1948-53 are presented in Table 1. The statistical analysis of yield data (Table 2) indicates that yields of first and second crop wheat were significantly affected by crop residue and fertilizer treatments. The analysis also indicates that, with respect to the first wheat crop, there was a significant interaction between crop residue and fertilizer treatments. This was not true of the second wheat crop.

In the first crop after breaking, yields were significantly greater following alfalfa and alfalfa-grass than following grass. This was apparently due to the lower supply of available nitrogen following grass than that following alfalfa. The first crop wheat yields after breaking alfalfa and alfalfa-grass also compared favourably with those after fallow. The yields following grass were significantly less than the yields after fallow.

The yields of first crop wheat in the grain-fallow rotation were not significantly affected by the crop residue treatments although burning straw and returning straw and ploughing down sweet clover as a green manure resulted in higher yields than the other three residue treatments.

TABLE 1.—MEAN YIELDS OF WHEAT (1948–1953) IN GRAIN-HAY AND GRAIN-FALLOW ROTATIONS AS AFFECTED BY CROP RESIDUES AND FERTILIZER TREATMENTS (Bushels per acre)

Crop residue treatments	First crop after breaking or fallow						Second crop after breaking or fallow					
	Check	11-48-0 @ 45 lb./acre	16-20-0@ 108 lb./acre	B.Y.M.@ 4 tons/acre	Means	L.S.D.	Check	11-48-0 @ 45 lb./acre	16-20-0 @ 108 lb./acre	B.Y.M. @ 4 tons/acre	Means	L.S.D.
In grain-hay rotation												
1. Alfalfa—return wheat stubble only—plough.	34.4	36.4	36.8	33.1	35.2		23.8	26.5	31.0	28.1	27.4	
2. Alfalfa—grass—return wheat stubble only—plough	30.7	33.7	35.5	35.4	33.8		23.0	27.0	31.5	24.5	26.5	
3. Grass mixture—return wheat stubble only—plough	25.6	27.3	33.1	26.1	28.0		19.4	23.7	25.7	22.4	22.8	
In grain-fallow rotation												
4. Return wheat stubble only—plough	32.4	35.4	36.6	35.8	35.0	4.6	20.0	23.8	28.6	23.1	23.9	4.6
5. Return wheat straw and stubble—disk and cultivate	31.4	34.0	37.6	31.8	33.7		18.4	20.3	24.5	18.5	20.4	
6. Return wheat straw and stubble—cultivate	32.4	34.5	36.8	35.4	34.8		16.3	18.9	24.1	19.7	19.7	
7. Return wheat straw and stubble—burn and cultivate	34.5	39.5	38.1	36.6	37.2		20.4	23.6	30.4	24.2	24.5	
8. Return straw and stubble—plough down sweet clover in fallow year	35.5	37.4	40.8	38.3	38.0		23.0	28.9	31.5	26.8	27.6	
Means	32.1	34.8	37.0	34.1			20.5	24.1	28.4	23.4		
L.S.D.	1.0						1.1					

TABLE 2.—MEAN SQUARES, OBSERVED AND NECESSARY F VALUES FOR SIGNIFICANCE IN WHEAT YIELDS (1948–1953)

Source of variance	Degrees of freedom	1st crop after breaking or fallow		2nd crop after breaking or fallow		Necessary F values	
		Mean squares	Observed F	Mean squares	Observed F	0.05	0.01
Years (reps)	5	3037.91	49.61	952.07	15.23	2.48	3.60
Residue treatments	7	216.84	3.54	217.25	3.48	2.29	3.20
Error A (years × res. treat.)	35	61.23		62.50			
Fertilizers	3	189.9	30.24	513.84	67.17	2.68	3.95
Fertilizers × res. treat.	21	11.06	1.76	6.05	0.79	1.65	2.02
Error B	120	6.28		7.65			

Apparently the effects of crop residues were minimized by the fact that they were almost completely decomposed during the fallow year. Establishment of reserves of available nitrogen and of soil moisture in fallow year also favoured relatively large and uniform yields.

Yields of the second wheat crop after breaking alfalfa were greater than the yields following grass by amounts which approached significance. This suggests that the effect of grass in reducing wheat yields persisted into second year.

The yields of second crop wheat in the grain-fallow rotation were greatly influenced by residue treatments. Lowest yields were obtained where straw and stubble were returned, whereas highest yields were obtained from sweet clover, green manure treatment. The higher yield for the green manure treatment as compared to burning straw and stubble suggests that it supplied sufficient additional nitrogen to more than offset the depressing effect of straw on available nitrogen.

Significant increases in yields of first and second crop wheat were obtained by applications of 16-20-0, 11-48-0 and barnyard manure in descending order of magnitude. All three fertilizer treatments effected greater yield increases in the second crop than in the first crop. Although the fertilizer treatments resulted in substantial yield increases they did not narrow the difference in yield between plots receiving different residue treatments.

Protein Data

The statistical analysis (Table 4) of the protein data summarized in Table 3 indicates that protein content in first crop wheat was significantly affected by the crop residue treatments but not by the fertilizer treatment. In second crop wheat it was fertilizer treatments and not the residue treatments which significantly affected protein content. However, it is doubtful whether the fertilizer effects are important since in no case was the mean for fertilizer treatment significantly different from that of the check. The analysis also shows that there was a significant interaction between the residue and fertilizer treatments in first and second crop wheat.

The protein content of the first wheat crop after alfalfa was significantly higher than that of the other residue treatments except for wheat from the green manured plots. The protein content of wheat after grass was significantly lower than that following all other treatments with the exception of treatments 4, 5 and 6. The same trends are also evident in the protein content of the second wheat crop after fallow or breaking. The highest protein contents were recorded after alfalfa and where sweet clover had been ploughed down in the fallow year while the lowest protein content was obtained following grass. However the magnitude of the difference was less than with the first crop after breaking and hence the residue treatments did not produce significant effects.

GENERAL DISCUSSION

The data presented indicate that yield of wheat is influenced by the supply of available nitrogen early in the season. The treatment with 16-20-0 which supplied only about 17 lb. of nitrogen per acre, increased

TABLE 3.—PROTEIN CONTENT OF WHEAT (1948–1953) GROWN IN GRAIN-HAY AND GRAIN-FALLOW ROTATIONS AS AFFECTED BY CROP RESIDUES AND FERTILIZER TREATMENTS (Mean per cent protein based on 13.5 per cent moisture)

Crop residue treatments	First crop after breaking or fallow						Second crop after breaking or fallow					
	Check	11-48-0 @ 45 lb./acre	16-20-0 @ 108 lb./acre	B.Y.M. @ 4 tons/acre	Means	L.S.D.	Check	11-48-0 @ 45 lb./acre	16-20-0 @ 108 lb./acre	B.Y.M. @ 4 tons/acre	Means	L.S.D.
In grain-hay rotation												
1. Alfalfa—return wheat stubble only—plough	13.0	13.3	13.2	13.0	13.1		12.3	12.4	12.0	12.2	12.2	
2. Alfalfa—grass—return stubble only—plough	12.3	12.5	12.4	12.3	12.4		11.8	11.7	11.8	12.2	11.9	Not significant
3. Grass—return wheat stubble only—plough	11.5	11.3	11.6	11.7	11.5		11.4	11.1	11.5	11.2	11.3	
In grain-fallow rotation												
4. Return stubble only—plough	11.7	12.2	11.8	12.4	12.0	0.6	11.3	11.6	11.1	12.0	11.5	
5. Return straw and stubble—disk and cultivate	11.7	11.9	12.1	11.4	11.8		11.2	11.6	11.6	10.9	11.3	
6. Return straw and stubble—cultivate	12.1	11.4	11.6	12.0	11.8		11.9	11.0	11.1	12.0	11.5	
7. Return straw and stubble—burn and cultivate	12.4	12.5	12.5	12.2	12.4		12.2	11.9	11.3	11.4	11.7	
8. Return straw and stubble—plough down sweet clover in fallow year	12.7	12.7	12.8	12.7	12.7		11.9	11.7	12.4	12.7	12.2	
Means	12.2	12.2	12.2	12.2			11.7	11.6	11.6	11.8		
	Not significant						0.2					

TABLE 4.—MEAN SQUARES, OBSERVED AND NECESSARY F VALUES FOR SIGNIFICANCE IN PROTEIN CONTENT OF WHEAT (1948–1953)

Source of variance	Degrees of freedom	1st crop after breaking or fallow		2nd crop after breaking or fallow		Necessary F values	
		Mean squares	Observed F	Mean squares	Observed F	0.05	0.01
Years (reps)	5	31.48	26.45	51.54	31.24	2.48	3.60
Residue treatments	7	7.44	6.25	2.93	1.78	2.29	3.20
Error A (reps × res. treat.)	35	1.19		1.65			
Fertilizers	3	0.06	0.46	0.77	3.08	2.68	3.95
Fertilizers × res. treat.	21	0.29	2.23	0.79	3.16	1.65	2.02
Error B	120	0.13		0.25			

yields particularly on the second crop after fallow or the first crop after breaking land from grass. However, it did not affect the protein content, apparently because the nitrogen was used up by increased early growth. This is in keeping with results reported by McNeal and Davis (3) who found that spring nitrogen applications increased yield but not protein content.

Protein content of wheat is influenced by crop residue treatments. These treatments apparently affect rate of nitrification throughout the growing season. Residues which nitrify rapidly and release greater amounts of available nitrogen during the growing season result in higher yields and protein content of wheat than those residues which nitrify slowly and release smaller amounts of available nitrogen. These results are in agreement with those reported by Peterson (6) who found that nitrogen is more effective in increasing protein content the nearer it is applied to harvest.

Under the conditions of this experiment, the use of legumes, either as green manures or for hay, results in higher yields and protein content of wheat than where these crops are not grown.

ACKNOWLEDGEMENTS

Acknowledgement is hereby made to J. H. Ellis, now retired, who initiated and directed the experimental work, and to L. H. Shebeski and J. D. Truscott, for advice regarding statistical treatment of the data and for reading the manuscript.

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SOME EFFECTS OF SOIL TEMPERATURE ON PHOSPHORUS REQUIREMENTS OF YOUNG CORN PLANTS IN THE GREENHOUSE[1]

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[Received for publication July 23, 1956]

ABSTRACT

Germinated corn seedlings were planted in Burford loam soil in 1-gal. glazed pots and allowed to grow for 8 weeks in the greenhouse. Two levels of phosphorus, 0 and 20 p.p.m P_2O_5, were used, along with a uniform treatment of nitrogen and potassium fertilizer. Carrier-free phosphorus-32 was placed in the bottom of the pot as compared with mixing throughout to indicate regions of root activity. One set of pots, consisting of four replications per treatment, was placed in a water bath averaging approximately 13° C. A corresponding set was placed on the greenhouse bench where temperature averaged approximately 20° C. Air temperature was the same for both sets.

Although the soil used for this study tested high in acid-soluble phosphorus and thereby suggested a low fertilizer phosphorus requirement, the use of phosphorus fertilizer significantly increased both the yield and phosphorus uptake of corn plants. Moreover, the relative increase for fertilizer was much greater under low temperature than under high temperature conditions. This was due to an actual reduction in phosphorus percentage in fertilized plants grown at the higher temperature while the reverse was true at the lower temperature level.

Root activity, particularly in the bottom portion of the pots, was reduced by low temperature, but phosphorus fertilizer partially overcame this effect. The consequence of these effects on growth of corn in the field, and on soil test correlation work, is mentioned.

INTRODUCTION

Pronounced response to small applications of superphosphate has been observed in corn at the Soils and Agricultural Engineering Farm at Guelph, Ontario. This response is confined to the early stage of growth, appearing first when the plants are about 3 weeks old, and extending through June. Untreated plants exhibit a marked visual phosphate deficiency through purpled leaves and retarded growth as compared to treated plants. Following the early growth stage, the visual deficiency disappears but the growth differential is maintained through pollination to maturity. The treated plants mature earlier and tend toward lower moisture in the ears. Yields may be increased if weather conditions favour pollination in these more advanced plants.

Since the level of available phosphorus is rated high on the soils of this farm, the reason for this type of response is of particular interest. The situation is presented where a phosphorus fertilizer requirement is indicated while soil tests call for no additional phosphorus. This report presents the results of a study of the contribution of soil temperature effects to this phenomenon.

LITERATURE REVIEW

In reviewing the literature pertaining to the effect of temperature on nutrient uptake, the contributions by Hagan (6) were taken as a basis for the work already reported. From these it would appear that very few

[1]Paper presented at the Canadian Society of Soil Science meeting, Toronto, June, 1956.
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studies on this subject have been undertaken. The work reported deals mainly with excised plant parts in nutrient solution rather than intact plants under normal growing conditions. Furthermore, the existing investigations deal mainly with nitrogen uptake by fruit trees.

Some of the more important physiological effects of lowered temperatures are decreased kinetic energy, fluidity of protoplasm, solubility of certain solids, and diffusion and reaction velocities. The consequences of these effects may be reduced respiration and translocation within the plant system. In roots a reduction in these processes reduces the energy and food available for root growth, and for nutrient absorption and assimilation.

Kramer and Currier (4) consider that permeability of the root cells influences absorption and that permeability is decreased by low temperature and low respiration rate. Hoagland and Broyer (3) point out that energy must be expended to transfer ions across cytoplasmic membranes against a concentration gradient. Thus a low temperature further reduces the ability of the root to absorb nutrients. The effect of low temperature in decreasing nutrient absorption has also been shown to be more pronounced under a low than under a high nutrient concentration in the substrate. Furthermore, the absorption of anions tends to be more dependent on temperature than is the adsorption of cations.

Variations in soil temperature may also affect nutrient uptake through changes in amount of root extension. When temperature is reduced below optimum, root growth and extension are also reduced. This may be due to reduced translocation of carbohydrates from the tops, or to reduced nutrient uptake from soil, or both. The relative contributions of these effects are not known (6).

The optimum soil temperature for the growth of corn roots is reported by Dickson (2) to be about 24° C. This is considerably above the optimum reported for forage and small grain crops. He also found this temperature optimum for the growth of tops during the early stages. Since this work was carried out before 1923, the behaviour of hybrid corn obviously was not reflected.

Nightingale (5) observed that the morphology of fruit tree roots was influenced by temperature. More root hairs appeared at temperatures below 24° C. This suggests that a measure of root activity rather than root weight may be necessary in the evaluation of temperature effects on nutrient uptake.

In soils low in available phosphorus, the initial effect of phosphorus fertilizer is considered to increase root growth (1, 7). Thus, in addition to increasing the amount of nutrient present in the root zone, these fertilizers may also increase the ability of the root system to forage for native soil nutrients.

In the present study the effect of soil temperature on root activity and phosphorus accumulation in the tops of corn plants over an 8-week period was considered. The ability of phosphorus fertilizer to modify these effects was also considered. The many effects of temperature on the uptake of other nutrients, and on the incidence of disease were not dealt with.

MATERIALS AND METHODS

The soil used in this study was a loam, pH 7.2, containing 480 lb. acid-soluble phosphorus per acre (P_2O_5 by .05N HCl at 1:50 ratio) and 130 lb. adsorbed phosphorus per acre (P_2O_5 by .05N NH_4 F at 1:50 ratio). The organic matter content was 3.0 per cent. It was taken from a field plot which had received no phosphorus fertilizer over a 5-year period.

One-gallon glazed pots were filled with 9 lb. of air-dry soil and placed in the greenhouse. Phosphorus-32 adsorbed on synthetic resin (Amberlite I R 4B) was mixed throughout the soil of one treatment and in the bottom inch of soil in a second treatment. Mono-ammonium phosphate was banded near the seed in addition to the tagged nutrient at the bottom of the pot in a third treatment. Approximately 100 uc phosphorus-32 was used per pot and represented an insignificant amount of nutrient. The rate of phosphorus banded was based on 20 p.p.m. P_2O_5. Ammonium sulphate was used to bring the nitrogen application to 10 p.p.m in all treatments. Potassium chloride was used to supply the potassium requirement.

Four germinated corn seeds of the variety Funks G-10 were planted per pot. One series of the above treatments with four replications each was placed on the greenhouse bench where air and soil temperatures averaged 20° C. A second series of these treatments was placed in a

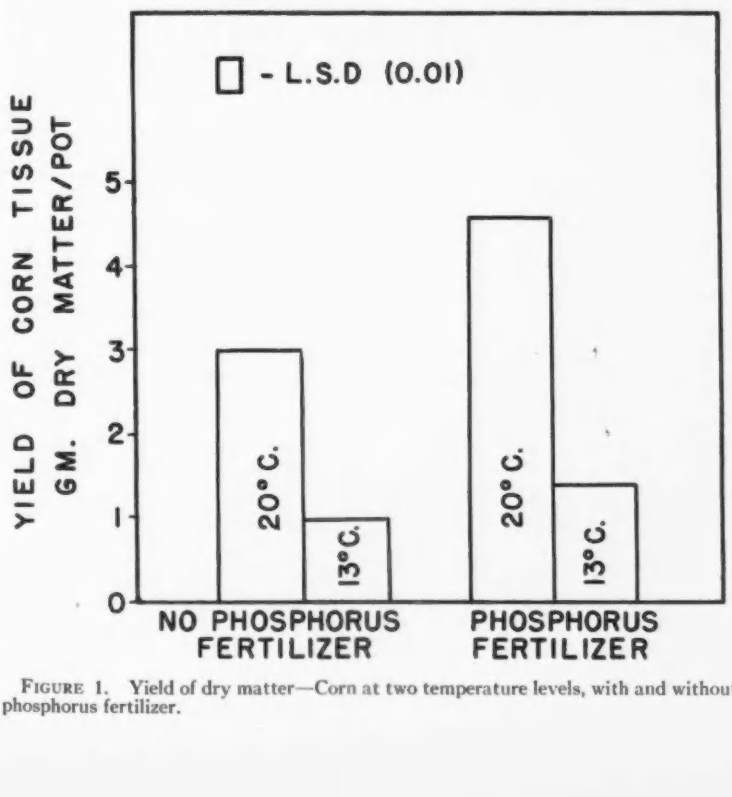

FIGURE 1. Yield of dry matter—Corn at two temperature levels, with and without phosphorus fertilizer.

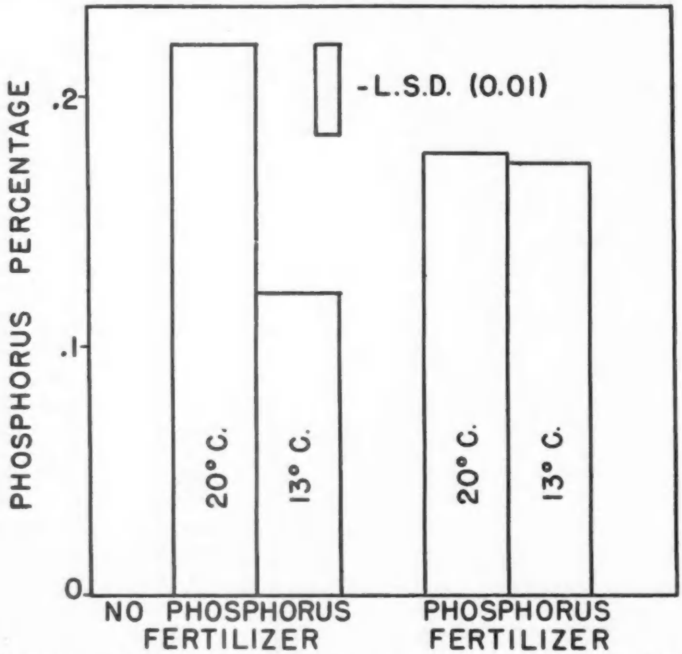

FIGURE 2. Phosphorus percentage—Corn at two temperature levels, with and without phosphorus fertilizer.

water bath where the temperature averaged 13° C. The bath was covered and the pots inserted through close-fitting openings so that the above-soil portions of the plants were subject to an environment similar to those on the open bench. Soil moisture was adjusted to the calculated field capacity by weighing once a week.

The plants were grown for 8 weeks, the tops harvested, and total yield of dry matter determined. Tissue samples were ashed at 525° C., the phosphorus content determined colorimetrically, and the phosphorus-32 activity ascertained by counting the digested tissue in a solution Geiger counting tube. Specific activity for each sample was calculated.

RESULTS AND DISCUSSION

The total yield of dry matter for treated and untreated pots at the two temperature levels is presented graphically in Figure 1. Phosphorus percentage, uptake, and phosphorus-32 activity are presented in Figures 2, 3, and 4.

The results of statistical analysis indicate significant differences between all yield values, and between phosphorus percentage values for individual treatments and treatment means where no phosphorus fertilizer was used. On phosphorus fertilized pots there was no difference in percentage between the two temperature levels. Total activities showed a significant difference between the two temperature levels, and between phosphorus-32 mixed throughout the pot and mixed in the bottom only.

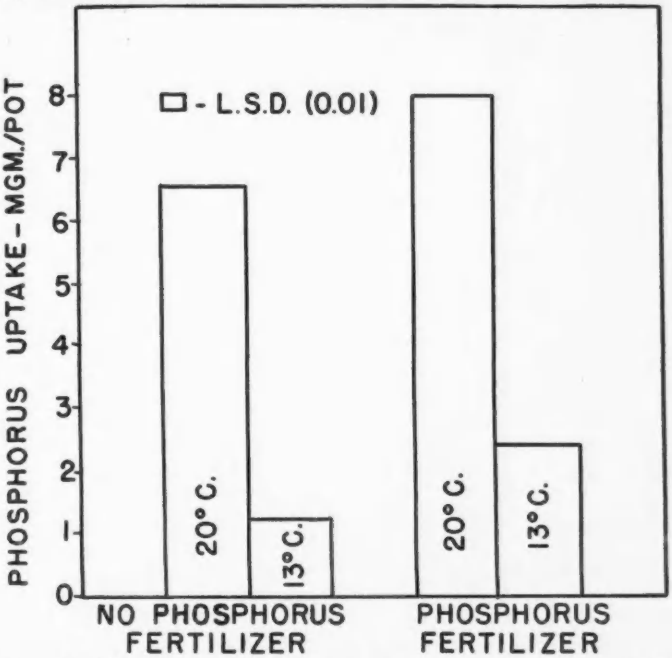

FIGURE 3. Phosphorus uptake—Corn at two temperature levels, with and without phosphorus fertilizer.

Banding phosphorus fertilizer with the corn did not significantly change the total activity. In each case there was a highly significant interaction between fertilizer treatment and temperature.

From the yield data in Figure 1 it is evident that low temperature depressed the growth of corn seedlings. This is keeping with the optimum temperature of 24° C. required for the early growth of this crop. It is also shown that phosphorus fertilizer significantly increased the yield at each temperature level.

Figure 2 indicates that the phosphorus percentage was decreased by phosphorus fertilizer at the higher temperature level, and was increased at the lower level. Thus phosphorus fertilizer tended to offset the difference in phosphorus percentage caused by low temperature. This lower percentage in fertilized plants grown at the higher temperature can only be explained through a growth stimulation due to banded fertilizer without a corresponding increase in phosphorus uptake.

Figure 3 gives the effect of temperature on total uptake of phosphorus by the tops of the plants. The relationship is similar to that for yield. Again, however, the greater uptake by fertilized plants at the higher temperature appears due entirely to yield increase, whereas the greater uptake at the lower temperature appears due mainly to an increase in phosphorus percentage.

Figure 4 illustrates the relationship between specific activities for the two temperature levels, for two fertility treatments, and for two place-

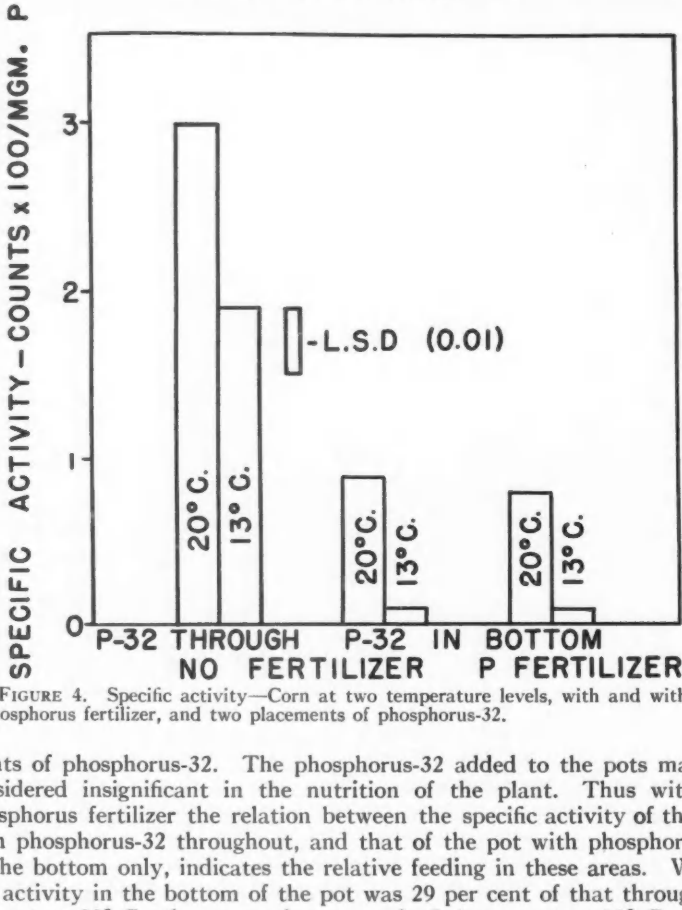

FIGURE 4. Specific activity—Corn at two temperature levels, with and without phosphorus fertilizer, and two placements of phosphorus-32.

ments of phosphorus-32. The phosphorus-32 added to the pots may be considered insignificant in the nutrition of the plant. Thus with no phosphorus fertilizer the relation between the specific activity of the pot with phosphorus-32 throughout, and that of the pot with phosphorus-32 in the bottom only, indicates the relative feeding in these areas. Where the activity in the bottom of the pot was 29 per cent of that throughout the pot at 20° C., the proportion was only 5.6 per cent at 13° C. This suggests that low temperature causes a pronounced restriction in root development in this area of the pot.

Normally the addition of phosphorus fertilizer would substantially lower the specific activity of plant material due to the increased dilution of phosphorus-32 with the stable isotope. In this instance, however, with the phosphorus-32 in the bottom of the pot, phosphorus fertilizer increased the total uptake but left the specific activity essentially unchanged. This suggests an indirect increase in uptake by the phosphorus fertilizer through stimulation of rooting in the lower region of the pot as well as a direct increase through uptake of the applied material.

These relationships assume considerable importance in regard to the early growth of corn in the field and its response to fertilizer. Aside from the depression in yield, the reduction in phosphorus percentage with the lower temperature suggests an increased phosphorus requirement under

such conditions. Effects such as these show where soil test correlations with crop response could fail. For instance, a soil giving no yield response in one season might respond during another.

These effects also support the practice of drilling soluble phosphorus fertilizer with the seed at planting, even although the soil level of available phosphorus appears adequate. Cool weather following germination may increase the plant's soil requirement during this stage of growth.

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THE EFFECT OF FARM AND GREEN MANURES ON THE FERTILITY OF BLACKEARTH-MEADOW CLAY SOILS[1]

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ABSTRACT

Green manure crops were ploughed down in the fallow year of a fallow, wheat, corn, wheat rotation to determine their effect on total organic carbon and nitrogen in the soil and on crop yields.

An average decrease of 27.9 per cent of the organic carbon and 15.9 per cent of the nitrogen in the soil occurred over a 25-year period. Under sweet clover and farm manure the levels of organic carbon and nitrogen were significantly higher than the levels of these constituents under fallow treatment. The levels of organic carbon and nitrogen were not significantly affected by weeds, buckwheat, corn, rye, peas and red clover green crop treatments.

There was little crop yield response to nitrogen-supplying green crops the first year after fallow. However, during recent years there was a gradual increase in yield response to nitrogen-supplying treatments in the second and third crops after fallow. This increased response to nitrogen probably reflected the gradual decline in the ability of the soil to supply nitrogen as total soil organic matter declined.

INTRODUCTION

A knowledge of the effect of various crop rotations on soil fertility is important to the development of a permanent agriculture in Western Canada.

Many investigators have reported changes in soil fertility occasioned by arable culture. Perhaps the earliest data on Western Canadian soils were presented by Shutt who originally in 1907 and again in 1925 (11), drew attention to the loss of nitrogen and organic matter from prairie soils under arable culture. Subsequently numerous soil scientists (2, 4, 7, 8) have reported decreases in organic matter due to cultivation of prairie soils.

Green manure crops have often been utilized to offset losses in organic matter. Pinck *et al.* (9) pointed out that green manure crops seldom, if ever, build up the supply of soil organic matter as they are turned under when succulent and the quantity of added material is small. However, soil scientists agree that, although cropping systems which include a 'soil building crop' do not necessarily maintain the organic carbon and nitrogen level of the soil, they do affect the rate of loss and the ultimate level of these constituents (3, 6). Pinck *et al.* (9) explained that the main functions of green manure crops are to "prevent erosion and leaching, improve the physical condition of the soil, supply active organic matter and available nitrogen over an extended period, fix nitrogen (if they are legumes) and incidentally help keep the carbon level from decreasing as fast as it presumably otherwise might do".

[1] Joint Contribution from the Department of Soils, University of Manitoba, and Experimental Farms Service, Canada Department of Agriculture. Based partly on a thesis submitted by the senior author to the Graduate School, University of Manitoba, in partial fulfilment of the requirements for the degree of Master of Science.

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The full value of green manure crops cannot be measured completely by the organic carbon and nitrogen content of the soil. A long-term change in these constituents does not necessarily reflect the short-term value of green manures which are included in the rotation to increase yield. Crop yields are a reflection of soil fertility and, therefore, provide a practical measure of the value of the green manure crops.

MATERIALS AND METHODS

A study of the effect of farm and green manures on crop yields and on the level of organic carbon and nitrogen in the soil was initiated in 1919 on the Fertility Field at the University of Manitoba. The soil types in this field are clay in texture and are members of the Fort Garry and Red River associations as described by Ehrlich *et al.* (5). The experiment consisted of a green crop—fallow, wheat, corn, wheat rotation laid out on four blocks, one for each year of the rotation. Each block was divided into 11 one-fortieth acre plots, permitting 3 check plots, 7 green crop treatments and 1 farm manure treatment. The treatments were arranged in a regular manner on each block as follows: check, weeds, buckwheat, spring rye, corn, check, peas, sweet clover, red clover, farm manure, check. The check plots were kept free of weeds throughout the summer. On the second plot, the weeds were allowed to grow until late June and then ploughed down. The buckwheat, spring rye, corn and peas were seeded in the spring in 6-inch drill spacings and ploughed in July. Sweet clover and red clover were seeded with the previous wheat crop and ploughed down in bloom. Rotted farm manure was applied at 10 tons per acre and ploughed down at the same time as the spring sown green crops. All crop residues excepting stubble were removed from the plots. In 1927, 1928, 1929 and 1930, other cereal crops were substituted for wheat on some blocks due to lateness of seeding. In 1951, alfalfa was substituted for sweet clover in an attempt to avoid sweet clover weevil damage.

The wheat harvested from each one-fortieth acre plot was weighed, and the yield calculated in bushels per acre. The corn crop was harvested for fodder and yield for each plot was computed in tons per acre green weight.

Soil samples were taken for organic carbon and nitrogen analyses in 1930, in 1948 and in 1955. Each plot was sampled to a 6-inch depth at four locations and a composite sample was prepared. Organic carbon was determined in 1930 by the wet combustion method of Robinson *et al.* (10). In 1948 and 1955, organic carbon was determined by a wet combustion method adapted from the methods of Adams (1) and Waynick (13). The Kjeldahl-Gunning-Arnold method was utilized throughout for the determination of nitrogen.

RESULTS AND DISCUSSION

Organic Carbon and Nitrogen

The percentages of organic carbon and nitrogen and the carbon-nitrogen ratios under various treatments in 1930, 1948 and 1955 are presented in Table 1. There was an over-all average decrease of 27.9 per cent of the organic carbon and 15.9 per cent of the nitrogen over the

TABLE 1.—STATUS OF ORGANIC CARBON AND NITROGEN IN THE SOIL IN 1930, 1948, AND 1955 UNDER GREEN CROP TREATMENTS AND FARM MANURE

	Check	Weeds	Buckwheat	Spring Rye	Corn	Check	Peas	Sweet clover	Red clover	Farm manure	Check	Mean
Per cent organic carbon												
1930	4.40	4.50	4.14	4.19	4.80	4.46	3.95	5.05	4.69	5.07	4.68	4.54
1948	3.25	3.48	3.43	3.49	3.68	3.79	3.65	3.98	3.88	4.13	3.58	3.67
1955	2.77	2.80	2.77	3.09	3.39	3.37	3.71	3.50	3.44	3.66	3.36	3.26
Per cent loss 1930-55	37.0	37.8	33.1	26.3	29.4	24.4	6.1	30.7	26.6	27.8	28.2	27.9
Per cent nitrogen												
1930	.365	.364	.326	.347	.381	.377	.357	.409	.380	.388	.379	.370
1948	.310	.323	.322	.313	.304	.343	.325	.358	.327	.338	.315	.325
1955	.282	.298	.292	.303	.309	.305	.322	.341	.327	.340	.304	.311
Per cent loss 1930-55	22.7	18.1	10.4	12.7	18.9	19.1	9.8	16.6	13.9	12.4	19.8	15.9
Carbon-nitrogen ratio												
1930	12.1	12.4	12.7	12.1	12.6	11.8	11.1	12.3	12.3	13.1	12.3	12.3
1948	10.5	10.8	10.7	11.2	12.1	11.0	11.2	11.1	11.9	12.2	11.4	11.3
1955	9.9	9.4	9.5	10.0	11.0	11.0	11.5	10.1	10.5	10.2	11.0	10.4

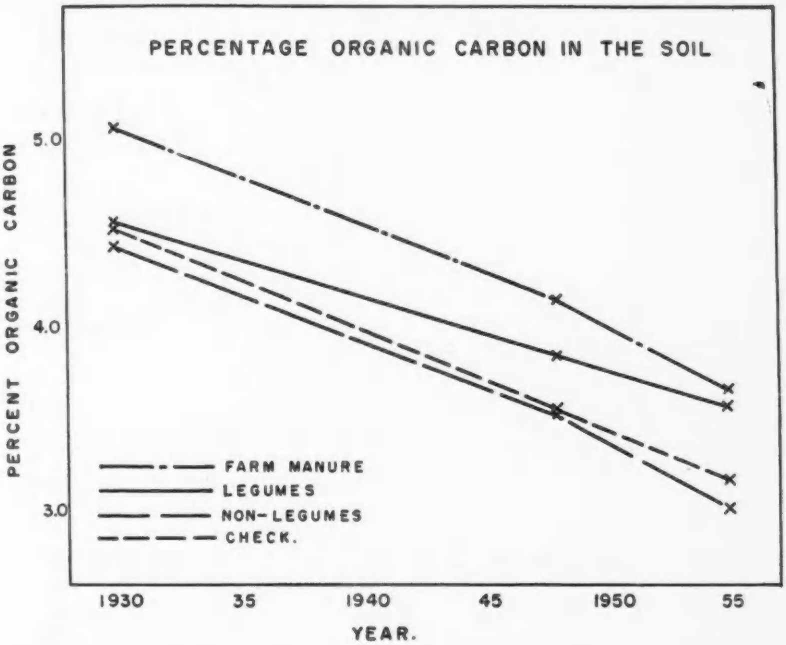

FIGURE 1. Diagram showing the percentage organic carbon in the soil in 1930, 1948, and 1955.

25-year period. Considerable variation in the levels of organic carbon and nitrogen was apparent under the different types of treatment. The treatments which tended to be highest in 1955 were among the highest in 1930. There was a gradual narrowing of the carbon-nitrogen ratio with time.

Graphs illustrating the effects of four general types of treatment (manure, legumes, non-legumes and check) upon the organic carbon and nitrogen levels in the soil are presented in Figures 1 and 2 respectively.

In Figure 1 a general decrease in the organic carbon levels under all types of treatment is indicated. However, the rate of loss of organic carbon from the soil apparently was retarded where legumes were used as green crops.

Although there was a decrease in the nitrogen level under all types of treatment as illustrated in Figure 2, the rate of loss of nitrogen was retarded where farm manure and legumes were utilized. The rate of loss of nitrogen from the soil was not affected by non-legume treatments.

A statistical analysis of the organic carbon and nitrogen results was conducted by making paired comparisons between the various treatments and the average check plots (see Table 2). As soil analysis was conducted on three occasions and on each occasion four results were obtained for each treatment (one from each block), there was a total of twelve results. To minimize the soil variation, a mean result from check plots 1 and 6 was

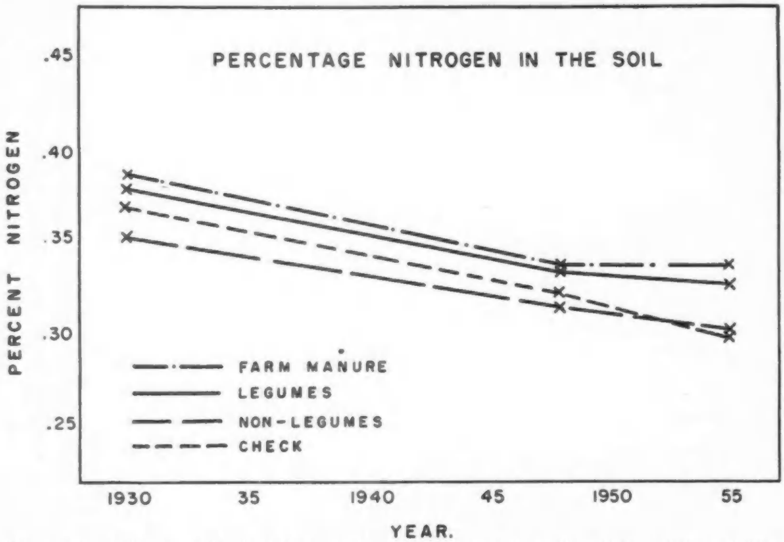

FIGURE 2. Diagram showing the percentage nitrogen in the soil in 1930, 1948, and 1955.

compared with results from the intervening treated plots 2, 3, 4, and 5. Similarly, a mean result from check plots 6 and 11 was compared with results from the intervening treated plots 7, 8, 9 and 10.

The sweet clover and farm manure treatments significantly affected the levels of organic carbon and nitrogen in the soil. Although other treatments resulted in organic carbon and nitrogen levels considerably different from the check plot results, these variations were not statistically significant.

Crop Yields and Soil Fertility

The crop yield trends for year 2 wheat, year 3 corn and year 4 wheat under farm manure and representative legume and non-legume treatments are presented in Figures 3, 4 and 5 respectively. Moving 10-year average figures were employed to minimize fluctuations in yield data which were caused by change in varieties, variations in climate and dates of seeding, lack of replication and other variable factors. The yield responses to treatment were calculated and are presented as yield increase or decrease related to the average of the check yields for any one 10-year period.

In the wheat crop after fallow (Figure 3) the legume and non-leguminous crops had little effect on crop yields. However, the rotted farm manure treatment resulted in consistent marked increase in crop yields. Since the fallow treatment the previous year developed considerable available nitrogen reserve through the decomposition of organic matter, there was little crop response to the nitrogen-supplying legume green crops. The increase in yield from the manure treatment was presumably due to response to phosphorus. The clay soils in question are unlikely to respond to potash, but in fertility experiments consistent response has been obtained from phosphate.

TABLE 2.—AVERAGE ORGANIC CARBON AND NITROGEN IN THE SOIL AND CALCULATED t VALUES

Plot number and treatment	Organic carbon		Nitrogen	
	Mean % all years	t value	Mean % all years	t value
Mean of check plots 1 + 6	3.68		0.331	
2. Weeds	3.59	0.69	0.328	0.33
3. Buckwheat	3.45	1.88	0.314	1.71
4. Spring rye	3.55	1.19	0.321	0.04
5. Corn	3.96	2.01	0.325	0.87
Mean of check plots 6 + 11	3.83		0.337	
7. Peas	3.77	0.28	0.334	0.46
8. Sweet clover	4.18	2.51*	0.369	6.50**
9. Red clover	3.99	1.26	0.344	0.85
10. Farm manure	4.29	4.20**	0.355	2.51*

** Significant at the 1% level.
* Significant at the 5% level.

TABLE 3.—EFFECT OF TREATMENT BY SELECTED PERIODS ON MEAN YIELDS OF WHEAT IN BUSHELS PER ACRE AND CORN IN TONS PER ACRE GREEN WEIGHT

Crop and period	Treatment			
	Check	Weeds	Sweet clover	Farm manure
Wheat after fallow				
1922-33	30.6	29.2	30.7	36.0
1930-39 (1935 excluded)	28.7	27.7	25.6	33.7
1940-49	38.6	37.5	38.8	43.7
Corn after wheat				
1922-33	7.92	8.15	8.44	8.11
1930-39	7.14	7.00	6.74	6.99
1940-49	8.39	8.90	9.80	9.84
Wheat after corn				
1922-33	28.2	25.5	28.9	30.1
1930-39 (1935 excluded)	26.8	25.8	26.9	27.7
1940-49	32.0	30.7	39.7	38.6

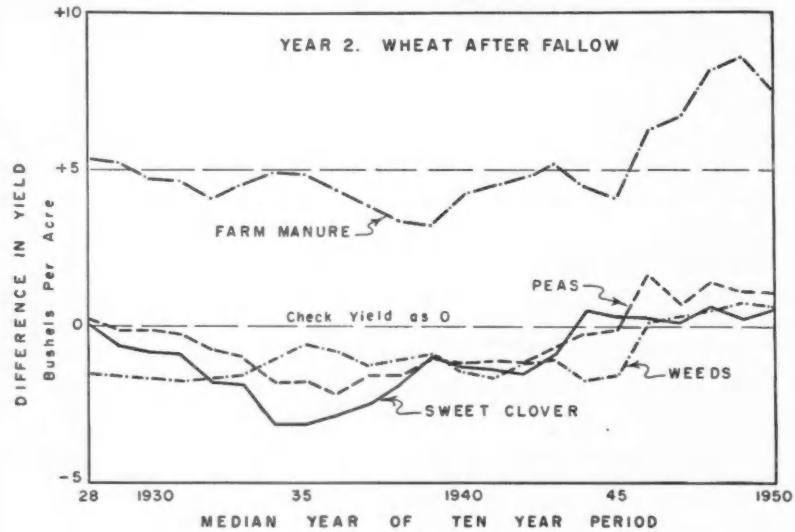

FIGURE 3. Diagram showing the moving 10-year average yield response of first crop wheat to representative green crop treatments and farm manure.

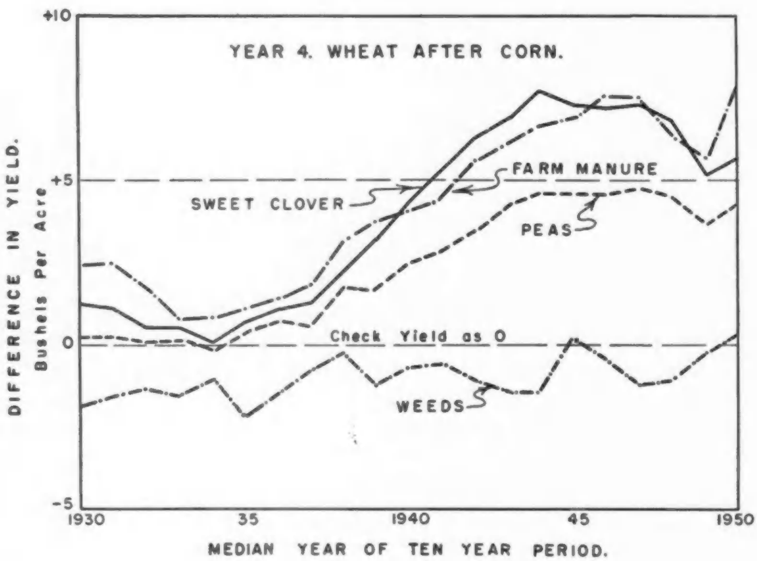

FIGURE 4. Diagram showing the moving 10-year average yield response of second crop corn to representative green crop treatments and farm manure.

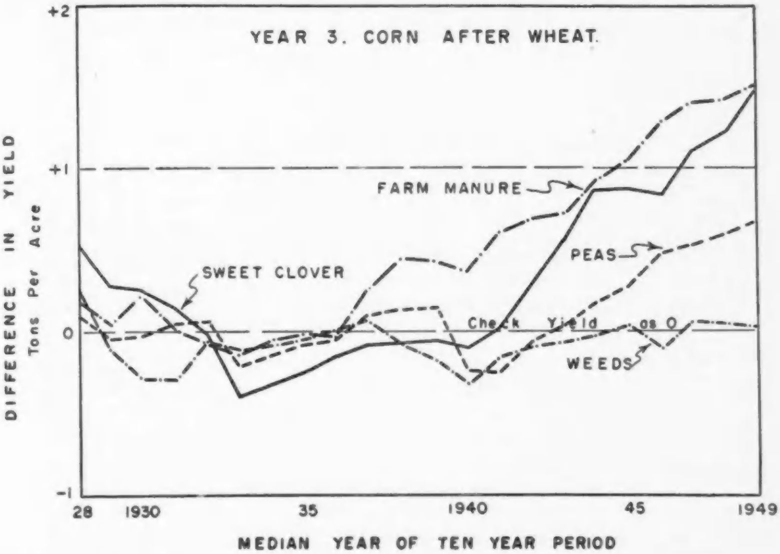

FIGURE 5. Diagram showing the moving 10-year average response of third crop wheat to representative green crop treatments and farm manure.

In the corn crop after wheat (Figure 4), the second crop after fallow, the use of legume green crops resulted in some response since 1942. There was a gradual increase in yield response to farm manure after 1937. Non-leguminous treatments had little effect on yield. Response to legume green crops was an indication that nitrogen supply was inadequate the second year after fallow. Response to the farm manure treatment was probably due to nitrogen and phosphorus fertilization. The increasing response from plots receiving nitrogen in recent years probably reflected the gradual decrease in total nitrogen in the soil.

In the wheat crop after corn (Figure 5), the third crop after fallow, the use of legume green crops and farm manure resulted in substantial yield response after 1937. The non-leguminous treatment had little effect on yield. The substantial response to nitrogen-supplying treatments indicated that the nitrogen supplied by the check and non-legume plots was inadequate to meet the demands of the growing crop. The gradual decline in the ability of the soil to supply nitrogen probably reflected the gradual decline in total organic matter of the soil.

Within the 1930-1939 period, green crops treatments, especially sweet clover, resulted in slight yield depression in the second year (Figure 3) and third year (Figure 4) after fallow. The mean yields during the 1930 to 1939 period (1935 excluded), as presented in Table 3, were less than during the 1940 to 1949 period. In an analysis of climatic data the average moisture deficiencies as determined after Thornthwaite (12) were found to be 19.7 cm. in the 1930 to 1939 period (1935 excluded) and 12.9 cm. in the 1940 to 1949 period for the growing months May, June and July. A significant linear regression ($r = 0.61$) was obtained between

average wheat yields third crop after fallow and total May, June and July moisture deficiencies. Apparently moisture was in more critical supply during the 1930 to 1939 period and the yield depressions after leguminous green crops may be explained in large part by moisture competition between the green crop and subsequent field crop.

CONCLUSIONS

There has been an over-all decrease of 27.9 per cent of the organic carbon and 15.9 per cent of the nitrogen during a period of 25 years. The levels of organic carbon and nitrogen have decreased regardless of method of green crop treatment. This decrease in soil fertility has been significantly retarded by the farm manure and sweet clover green crop treatments.

There was considerable yield response in recent years to the nitrogen supplied by nitrogen-fixing green crops and farm manure. This response reflected the gradual decline in the ability of the soil to supply nitrogen as total soil organic matter decreased. Although legume green crops did not maintain soil organic carbon and nitrogen, they provided a sufficient supply of nitrogen throughout the crop rotation to maintain relatively high yields provided that the moisture supply was adequate.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the contribution of J. H. Ellis who initiated the experiment and who, until his retirement, directed the experimental work; and the assistance of J. D. Truscott, of the Plant Science Department, University of Manitoba, who outlined methods of statistical analysis.

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A STAINING METHOD FOR THE QUANTITATIVE DETERMINATION OF FELDSPARS IN ROCKS AND SANDS FROM SOILS[1]

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ABSTRACT

A speedy and accurate staining procedure for the quantitative determination of the feldspars in rocks and sands of soils is proposed. The minerals are treated, by direct contact, with 48 per cent hydrofluoric acid, and then immersed in a concentrated sodium cobaltinitrite solution which stains the potash feldspars yellow. This treatment is followed by immersion in a buffered hematein solution which stains the plagioclase feldspars purple. The depth of colour on the plagioclase depends upon the position in the isomorphous series. Quartz, gypsum and calcite are not affected by the treatment.

The quantity of the potash and plagioclase feldspar present is then easily determined by grain counts under the petrographic microscope.

INTRODUCTION

Speed and accuracy may be increased in the quantitative determination of the different feldspars in rocks or grains derived from them, or in sands, by decomposing the surface of the minerals with hydrofluoric acid, and then very carefully immersing in staining solutions.

Gabriel (1) used a solution of concentrated sodium cobaltinitrite for the quantitative determination of potash feldspars and Graham (2) used a 0.1 per cent solution of malachite oxalate for the quantitative determination of plagioclase feldspars following a pretreatment with hydrofluoric acid vapour.

The method herein was developed to determine both potash and plagioclase feldspars in the same sample with one treatment of hydrofluoric acid in direct contact with the mineral grains. After the treatment with hydrofluoric acid, the minerals are immersed in a concentrated sodium cobaltinitrite solution to stain the potash feldspars yellow, and then immersed in a buffered hematein solution to stain the plagioclase feldspars purple.

METHOD

Reagents

Sodium cobaltinitrite solution. Dissolve 1 gm. of sodium cobaltinitrite reagent in 4 ml. of distilled water.

Hematein solution. Dissolve 0.05 gm. of hematein in 100 ml. of 95 per cent ethanol.

Buffer solution. Dissolve 20 gm. of sodium acetate ($NaC_2H_3O_2 \cdot 3H_2O$) in 100 ml. of distilled water, then add 6 ml. glacial acetic acid and dilute the whole to 200 ml. The solution is approximately 0.5N in acidity, and is buffered at pH 4.8.

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The minerals of the specific gravity fraction < 2.70 (quartz and feldspar group) of the crushed rock or sand sample, ground to pass a 65-mesh sieve, are treated by direct contact with 48 per cent hydrofluoric acid in a lead crucible for a period of 2 minutes. The acid is diluted immediately with distilled water and the supernatant liquid siphoned off. The sample is well dispersed over the bottom of the crucible, one layer deep, then a concentrated sodium cobaltinitrite solution is added and allowed to remain in contact with the mineral grains for 1 minute. The sample is then washed free of the solution with distilled water by siphoning off the supernatant liquid.

To the sodium cobaltinitrite treated sample is added 10 drops of hematein solution followed by 5 drops of buffer solution. The whole is mixed well by swirling the crucible for 2 to 3 minutes. The solution is allowed to remain in contact with the mineral grains for 5 minutes. The sample is then washed free of the solution with 95 per cent ethanol (the supernatant liquid was siphoned off) and finally washed twice with acetone, and dried.

The minerals are now ready for microscope examination and grain counts.

RESULTS AND DISCUSSION

The cobaltinitrite reagent produces on the potash feldspars a precipitate of yellow potassium cobaltinitrite which clings tenaciously to them. No precipitate is formed on the plagioclase feldspars.

The hematein reagent produces a purple stain on the plagioclase feldspars, the purple colour resulting from the reaction of the hematein with aluminum. The effect of the hematein on the potash feldspars is very slight and does not interfere with the predominantly yellow colour of the potassium cobaltinitrite.

Both the purple and yellow colours change with time if exposed to the air, and are easily removed by abrasion.

After this simple staining treatment the potash feldspars are intensely yellow and the plagioclase feldspars are purple. The depth of colour depends on the position in the isomorphous series, the colour being greatest for anorthite, successively lighter with less calcic feldspars, and lightest for

TABLE 1.—EFFECTS OF DIFFERENTIAL STAINING OF VARIOUS COMMON MINERALS OF THE SPECIFIC GRAVITY FRACTION < 2.70 IN ROCKS AND SANDS FROM SOILS

Mineral	Sodium cobaltinitrite	Hematein
Quartz	None	None
Gypsum	None	None
Calcite	None	None
Chlorite	None	Greenish purple
Orthoclase	Yellow	None
Microcline	Yellow	None
Anorthite	None	Deep purple
Labradorite	None	Medium to deep purple
Andesine	None	Medium purple
Oligoclase	None	Light to medium purple
Albite	None	Light purple

albite. When subjected to the same treatment, quartz, gypsum and calcite remain white to transparent; chlorite, if present, yields a purplish precipitate with hematein but the original green shows through giving the grains a decided greenish shade. The percentage of the potash and plagioclase feldspars are then easily determined by grain counts under the petrographic microscope.

Table 1 shows the effects of differential staining of various common minerals of the specific gravity fraction < 2.70 found in the rocks and sands from soils.

Minerals of known species, which are likely to be present in a sample, should be carried through the staining procedures to check the reagents and to act as standards.

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WET SIEVING APPARATUS FOR STABILITY ANALYSIS OF SOIL AGGREGATES[1]

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ABSTRACT

The design of van Bavel's wet sieving apparatus for soil aggregate stability analysis has been modified. A different sieve arrangement and a deeper tub are advantageous. Principles of operation are given for the modified unit.

The wet sieving technique to measure the percentage of water-stable aggregates in soils is widely used. In this paper a compact wet sieving apparatus is described which may prove valuable to workers interested in building similar equipment.

The design of this machine (Figure 1) is a modification of that described by van Bavel (1). It has a different sieve arrangement and a deeper tub. Six 5-inch sieves are used in each nest and held together by means of brass rods and an aluminum collar at the top. The sieve nest can be lowered at an angle into the water through a hole in the aluminum top plate, thus eliminating air locks in the sieves. A shoulder edge on the collar suspends the sieve nest from the aluminum plate, and permits good stability of the sieves. The tub does not have to be emptied prior to each run of analyses. The aluminum top plate can be removed to facilitate the cleaning of the tub. The water level in the tub during operation is kept constant by adding water or draining it through an overflow device.

The shaft and aluminum plate are oscillated vertically at the rate of 29.2 strokes per minute by means of a reduction motor and suitable eccentric. The cost of materials for the construction of this machine was $225.00 and approximately 45 hours of labour were required. Complete engineering drawings are available for distribution.

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[1]Contribution from the Division of Field Husbandry, Soils and Agricultural Engineering, Experimental Farms Service.

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FIGURE 1. Complete apparatus with one nest of sieves being inserted in the tub.

PHOSPHORUS AND POTASSIUM SUPPLY FOR ALFALFA IN SOILS SAMPLED AT DIFFERENT DEPTHS[1]

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ABSTRACT

Results of a greenhouse experiment, comprising soil samples taken at three depths from each of six locations in eastern Ontario, indicated that the phosphorus-supplying power of the surface was considerably greater than that of the corresponding subsurface samples of four of the soils. The relative amounts of total phosphorus in surface and subsurface samples varied with the soils, the most pronounced variation being an increase in a sandy soil with depth. The proportion of the total phosphorus found in organic form varied from 18 to 56 per cent in the surface and from 5 to 33 per cent in the subsurface samples. The amounts of acid-soluble phosphorus extracted from five of the soils increased with depth. The amounts of $NaHCO_3$-soluble phosphorus were higher in the surface than in the subsurface samples of five of the soils. The values for acid-soluble phosphorus in five of the soils and for $NaHCO_3$-soluble phosphorus in three of the soils were not in agreement with greenhouse results.

The data from the greenhouse experiment did not indicate a pronounced difference between the potassium-supplying powers of corresponding surface and subsurface samples. Exchangeable potassium did not vary appreciably between surface and subsurface samples of four of the soils but decreased in two of the soils with depth. Water-soluble potassium decreased with depth in most instances.

INTRODUCTION

Although it is generally recognized that the subsoil may influence plant growth appreciably under field conditions, information on the nutrient-supplying power of soils in relation to depth is meagre. Accordingly, in the fall of 1954, greenhouse tests were initiated for the purpose of assessing the supplies of phosphorus and potassium for alfalfa in soil samples collected at three depths from each of six locations in the Ottawa district. The surface and subsurface soil layers were compared on the basis of chemical properties, the yield of alfalfa grown with and without additions of phosphorus and potassium and the uptake of these nutrients by the crop.

EXPERIMENTAL PROCEDURE

Soil samples at three depths were collected from two fields located on Carp clay loam, and from one field on each of North Gower clay loam, Grenville loam, Castor silt loam and Rubicon sand in Carleton county, Ontario. These soils have been described elsewhere (1) but, for convenience, the following brief descriptions are given: (1) *Carp clay loam*, an imperfectly drained weakly developed grey brown podzolic soil; (2) *North Gower clay loam*, a poorly drained dark grey gleisolic soil; (3) *Grenville loam*, a well drained brown forest soil on till; (4) *Castor silt loam*, a poorly drained dark grey gleisolic soil; (5) *Rubicon sand*, an imperfectly drained podzol

[1] Joint contribution from Chemistry Division, Science Service, and Field Husbandry Division, Experimental Farms Service, Canada Department of Agriculture, Ottawa, Ont. (Contribution No. 338, Chemistry Division).

developed on an undulating plain. Except for the Grenville, all of these soils are of lacustrine or alluvial origin. One of the fields designated as (R) on Carp clay loam and the field on Castor silt loam were managed as pastures for many years. The remaining fields selected for sampling were under cultivation. The samples represented three soil layers and were taken at the depths specified in the tables. Most of the soils selected for this study did not show marked profile differentiation.

The samples were air-dried, passed through a half-inch mesh sieve, mixed and placed in glazed gallon pots on a volume basis. Samples of the air-dried soil were passed through a 2-mm. sieve and retained for analyses. In the greenhouse test, the treatments relevant to this discussion were: (1) potassium chloride at the rate of 200 lb. of K_2O per acre; (2) calcium dihydrogen phosphate at the rate of 200 lb. of P_2O_5 per acre; and (3) a combination of (1) and (2). Ammonium nitrate was added to all pots at the rate of 10 lb. of N per acre. The fertilizers were placed in the soil in a layer at a depth of 2 inches. Treatments were replicated six times and were randomized within each set of three samples representing a soil.

Inoculated Grimm alfalfa was seeded and later thinned to 10 plants per pot. Four crops of alfalfa in the bloom stage were harvested. After the first cutting of alfalfa was made, borax was added to all pots at the rate of 40 lb. per acre.

Composite samples of the material from the six replicates of each treatment were ground in a Wiley mill and organic matter was destroyed by digestion with sulphuric, nitric and perchloric acids as described by Piper (7). Phosphorus was determined by the method of King (2) and potassium by the micromethod described by Peech *et al.* (6).

The pH of the soil was determined by means of a glass electrode using a 1 : 1 soil : water ratio. Exchange capacity before and after oxidation of the samples with hydrogen peroxide, exchangeable potassium, total nitrogen and carbon contents of the soils were determined according to the procedures of Peech *et al.* (6). To extract water-soluble potassium, 1 : 2.5 soil : water suspensions were shaken for 10 minutes and allowed to stand overnight. The procedure for estimating potassium in the extract was similar to that employed for exchangeable potassium. Total soil phosphorus was determined by the method of King (2) after acid digestion by the procedure of Shelton and Harper (8). The procedure of Mehta *et al.* (3) was used to determine the total organic phosphorus content of the soils. Acid-soluble phosphorus was determined by the method of Truog (9), and inorganic $NaHCO_3$-soluble phosphorus by the method of Olsen *et al.* (4). Inorganic plus organic $NaHCO_3$-soluble phosphorus was determined by the method of King (2), after oxidation of a portion of the extract with perchloric acid. The amounts of organic $NaHCO_3$-soluble phosphorus were obtained by difference.

RESULTS AND DISCUSSION

Chemical Properties of Soils

Analyses reported in Table 1 show some general characteristics of the soils in relation to depth. In most instances, the pH values for the surface samples were slightly lower than those obtained for the corresponding subsurface samples. With increasing depth, the carbon and nitrogen

TABLE 1.—SOME CHEMICAL CHARACTERISTICS OF THE SOILS

Depth	pH	Exchange capacity		Carbon	Nitrogen	C : N ratio
		Total	Organic			
in.		m.e./100 gm.		%	%	
		North Gower Clay Loam				
0– 7	7.6	27.3	9.3	2.77	0.30	9
7–14	7.8	18.2	1.4	0.64	0.09	7
14–21	7.8	16.6	0.4	0.30	0.04	8
		Carp Clay Loam (R)				
0– 7	6.1	36.6	11.6	4.11	0.39	11
7–14	6.6	32.1	6.9	1.59	0.15	11
14–21	6.6	26.2	4.2	0.86	0.07	12
		Carp Clay Loam (S)				
0– 8	6.6	37.6	12.8	3.50	0.28	13
8–15	7.0	33.9	7.5	1.37	0.10	14
15–24	7.0	26.0	2.7	0.60	0.04	15
		Grenville Loam				
0– 6	7.3	21.7	10.9	3.28	0.28	12
6–17	7.5	14.8	2.7	1.33	0.13	10
17–24	7.9	7.0	0.1	0.80	0.07	11
		Castor Silt Loam				
0– 6	7.1	6.8	4.7	1.78	0.12	15
6–12	7.1	3.3	0.5	0.65	0.04	16
12–20	7.3	6.3	0.9	0.39	0.02	20
		Rubicon Sand				
0– 6	5.4	6.9	3.7	1.81	0.10	18
6–12	5.3	5.0	2.4	0.86	0.05	17
12–18	5.8	2.7	0.2	0.35	0.03	12

contents decreased but there was no appreciable variation in C : N ratios except in Castor silt loam and Rubicon sand. The total and organic exchange capacities of five of the soils decreased consistently with depth. In Castor silt loam, the organic exchange capacity of the lower subsurface layer was low but the total exchange capacity of the sample was similar to that obtained for the surface sample. Evidently, the contribution of the mineral portion of this soil to exchange was greater in the lowest layer than in the surface. The percentage of the total exchange capacity attributed to organic matter varied from 32 to 69 per cent in the surface samples; from 8 to 48 per cent in the middle layer; and from 1 to 16 per cent in the samples taken at the greatest depth.

The amounts of total, organic, $NaHCO_3$-soluble, and acid-soluble phosphorus extracted from the soils are presented in Table 2. The relationship between the amounts of total phosphorus and depth of sampling varied between soils. The amounts of total phosphorus in the surface samples of

TABLE 2.—AMOUNTS OF PHOSPHORUS IN THE SOILS

Depth	Total P	Organic P	Organic P as per cent of total P	Available phosphorus		
				$NaHCO_3$-soluble		Acid-soluble
				Inorganic	Organic	
in.	%	p.p.m.		p.p.m.	p.p.m.	p.p.m.
North Gower Clay Loam						
0– 7	0.12	392	32	8.3	11.7	206
7–14	0.09	136	14	3.4	1.5	280
14–21	0.10	96	10	3.4	0.2	304
Carp Clay Loam (R)						
0– 7	0.13	575	45	12.4	28.3	170
7–14	0.11	295	28	5.4	9.4	254
14–21	0.11	175	17	5.6	2.1	338
Carp Clay Loam (S)						
0– 8	0.10	437	44	17.7	17.8	236
8–15	0.09	235	26	5.9	3.2	296
15–24	0.11	207	19	3.1	2.1	357
Grenville Loam						
0– 6	0.06	342	56	6.6	9.7	26
6–17	0.06	206	33	5.0	4.6	13
17–24	0.06	83	13	2.1	2.8	8
Castor Silt Loam						
0– 6	0.09	155	18	3.9	12.8	61
6–12	0.11	88	8	2.4	3.8	150
12–20	0.12	59	5	2.0	1.6	192
Rubicon Sand						
0– 6	0.05	104	22	4.7	17.7	10
6–12	0.09	91	10	5.7	5.3	14
12–18	0.11	70	6	3.9	3.3	30

North Gower clay loam and Carp clay loam (R) were slightly higher than those obtained for the corresponding subsurface samples. On the other hand, the surface sample of Castor silt loam contained slightly less, and that of Rubicon sand considerably less, total phosphorus than was found in the corresponding subsurface samples. The total phosphorus contents of Grenville loam and the surface sample of Rubicon sand were considerably less than those of the other samples.

The organic phosphorus contents of the soils decreased with depth. In the surface samples, the amounts of organic phosphorus represented from 18 to 56 per cent of the total phosphorus present, whereas in the subsurface samples, the values for organic phosphorus varied from 5 to 33 per cent of those for total phosphorus. The amounts of organic phosphorus were considerably less in Castor silt loam and Rubicon sand than in the other soils. The decrease in organic phosphorus with depth was less

marked than that reported for carbon and nitrogen in Table 1. The average C: organic P ratio for the surface samples was 105 as compared with 61 for the subsurface samples. The average N: organic P ratio was 8.0 for the surface samples and 4.9 for the subsurface samples. C: organic P and N: organic P ratios reported for seven Iowa soils by Pearson and Simonson (5) were lower in many instances in the surface layers than in those at greater depth. In one of two grey brown podzolic profiles included in the study, however, the C: organic P and N: organic P ratios were considerably lower in the deeper layers than in the surface.

Estimates of available phosphorus in relation to depth varied somewhat with soil but more particularly with the method employed. In the clay loam soils, the amounts of inorganic phosphorus soluble in $NaHCO_3$ were much higher in the surface than the lower layers. In Grenville loam and Castor silt loam there was a slight decrease in inorganic $NaHCO_3$-soluble phosphorus with depth, while in Rubicon sand the values showed no consistent trend. Organic phosphorus soluble in $NaHCO_3$ decreased in all soils with depth. The differences between the surface and subsurface layers were pronounced. $NaHCO_3$ extracted more organic than inorganic phosphorus from the surface samples. The proportion of the total organic phosphorus soluble in $NaHCO_3$ was greater in the surface samples of Castor silt loam and Rubicon sand than in the corresponding samples of the other soils. In contrast to the results obtained with the $NaHCO_3$ method, acid-soluble phosphorus in all soils but Grenville loam increased consistently with depth. This variation in acid-soluble phosphorus with depth was not closely related to soil reaction. It may be noted, however, that the total inorganic phosphorus as represented by the difference between total and organic phosphorus increased with depth of sampling.

TABLE 3.—AMOUNTS OF EXCHANGEABLE AND WATER-SOLUBLE POTASSIUM IN SOILS

Approx. depth	Exchangeable K		Water-soluble K	Exchangeable K		Water-soluble K
in.	m.e. per 100 gm.	as per cent of exch. cap.	m.e. per 100 gm.	m.e. per 100 gm.	as per cent of exch. cap.	m.e. per 100 gm.
	North Gower Clay Loam			*Carp Clay Loam (R)*		
0–7	0.31	1.14	0.011	0.47	1.28	0.020
7–14	0.29	1.59	0.010	0.41	1.27	0.007
14–21	0.31	1.87	0.008	0.45	1.71	0.006
	Carp Clay Loam (S)			*Grenville Loam*		
0–7	0.42	1.12	0.013	0.21	0.97	0.012
7–16	0.48	1.41	0.008	0.14	0.95	0.007
16–24	0.44	1.69	0.008	0.09	1.29	0.007
	Castor Silt Loam			*Rubicon Sand*		
0–6	0.05	0.73	0.009	0.24	3.48	0.049
6–12	0.03	0.91	0.007	0.10	2.00	0.024
12–19	0.06	0.95	0.004	0.08	2.96	0.016

Data on exchangeable and water-soluble potassium in the soils are presented in Table 3. The amounts of exchangeable and particularly water-soluble potassium in Rubicon sand were relatively high for a sandy soil. In Grenville loam and Rubicon sand, exchangeable potassium decreased with depth, but in the other soils there were no consistent variations in the amounts of this form of potassium. The degree of saturation of the exchange complex with potassium increased with depth in the clay loam soils in particular and to a lesser extent in Grenville loam and Castor silt loam. Water-soluble potassium decreased with depth in most instances. This decrease in water-soluble potassium with depth tended to be associated with an increasing degree of potassium saturation even in the clay loam soils where exchangeable potassium did not vary appreciably. For similar depths of sampling, however, there was some tendency for higher amounts of water-soluble potassium to occur in the soils having the higher degree of potassium saturation.

TABLE 4.—YIELD, PHOSPHORUS CONTENT AND UPTAKE OF PHOSPHORUS BY ALFALFA IN SOILS SAMPLES AT THREE DEPTHS

Depth	Yield per pot		Phosphorus content		Uptake of P per pot		
	K added	PK added	K added	PK added	K added	PK added	K added × 100 / PK added
in.	gm.	gm.	%	%	mgm.	mgm.	
			North Gower Clay Loam				
0– 7	28.0	69.3	0.14	0.22	39.2	153	26
7–14	5.5	66.3	0.15	0.20	8.3	133	6
14–21	5.4	64.9	0.16	0.21	8.6	136	6
L.S.D. (0.05)	5.9		—		8.6		
			Carp Clay Loam (R)				
0– 7	31.1	48.8	0.15	0.23	46.7	112	42
7–14	28.7	52.5	0.15	0.23	43.1	121	36
14–21	36.4	54.8	0.17	0.23	61.9	126	49
L.S.D. (0.05)	6.2		—		9.5		
			Carp Clay Loam (S)				
0– 8	46.3	59.5	0.19	0.25	88.0	149	59
9–15	15.9	52.4	0.13	0.19	20.7	100	21
15–24	12.8	52.2	0.17	0.17	21.8	89	25
L.S.D. (0.05)	6.5		—		9.4		
			Grenville Loam				
0– 6	24.7	51.9	0.14	0.21	34.6	109	32
6–17	6.7	38.2	0.12	0.24	8.0	92	9
17–24	2.6	53.1	0.12	0.20	3.1	106	3
L.S.D. (0.05)	4.2		—		5.8		
			Castor Silt Loam				
0– 6	5.9	38.2	0.15	0.26	8.9	99	9
6–12	1.4	30.3	0.16	0.29	2.2	88	3
12–20	12.9	33.4	0.17	0.32	21.9	107	20
L.S.D. (0.05)	3.1		—		5.4		
			Rubicon Sand				
0– 6	6.5	17.7	0.17	0.21	11.1	37	30
6–12	1.1	10.7	0.13	0.25	1.4	27	5
12–18	1.2	20.7	0.12	0.24	1.4	50	3
L.S.D. (0.05)	2.9		—		4.1		

Greenhouse Experiment

The yield, phosphorus content, and uptake of phosphorus by alfalfa grown in the soil samples taken at different depths are presented in Table 4. When treated with both phosphorus and potassium, several of the subsurface samples produced yields which were similar to or only slightly lower than those obtained for corresponding surface samples. With addition of potassium only, however, the yields for the subsurface samples of four of the soils were considerably lower than those for the corresponding surface samples. Application of phosphorus increased the yields significantly on all samples but the effect was more pronounced on the subsurface than on the surface samples of North Gower clay loam, Carp clay loam (S) and Grenville loam.

The average phosphorus content of the crop was increased from 0.15 per cent where no phosphorus fertilizer was used to 0.23 per cent where phosphorus was added.

The uptake of phosphorus by the plants in relation to depth of sampling varied with treatment. Where phosphorus and potassium were added, the uptake of phosphorus from the lower subsurface samples of Rubicon sand, Castor silt loam and Carp clay loam (R) exceeded that of the corresponding surface samples, by differences which were significant. The uptake from the middle layer of the latter soil exceeded that for the surface sample by a difference which approached significance. The uptake for the remaining subsurface samples ranged from 59.6 to 97.4 per cent of that obtained for the corresponding surface sample.

With addition of potassium only, the plants removed more phosphorus from the lower subsurface than from the surface sample of Carp clay loam (R), and there was no significant difference between the uptake values for the middle and surface layers. The uptake from the lower subsurface sample of Castor silt loam was considerably higher than that from the surface sample. The amounts of phosphorus removed by the plants from the remaining subsurface samples receiving no phosphate fertilizer varied from 8.9 to 24.8 per cent of that removed from the corresponding surface sample.

Application of phosphorus increased the uptake of phosphorus by the crop considerably. When the influence of phosphorus fertilizer on uptake was assessed on the basis of uptake for the K treatment expressed as a percentage of that for PK, it was evident that the response to applied phosphorus was greater in the subsurface than in the surface samples of North Gower clay loam, Carp clay loam (S), Grenville loam, and Rubicon sand. The values showing response to phosphate applied to the different layers of Carp clay loam (R) were not widely different. The response to applied phosphorus was much less in the lower subsurface than in the other samples of Castor silt loam.

The data in Table 5 show the yield, potassium content and uptake of potassium by alfalfa in the samples taken at different depths. With addition of fertilizer containing phosphorus but no potassium, the yields were much more satisfactory and varied considerably less between surface and subsurface samples than those reported for the K treatment in Table 4. With addition of phosphorus only the subsurface samples of the clay loam

TABLE 5.—YIELD, POTASSIUM CONTENT AND UPTAKE OF POTASSIUM BY ALFALFA IN SOILS SAMPLED AT THREE DEPTHS

Depth	Yield per pot		Potassium content		Uptake of K per pot		
	P added	PK added	P added	PK added	P added	PK added	P added × 100 / PK added
in.	gm.	gm.	%	%	mgm.	mgm.	
North Gower Clay Loam							
0– 7	57.6	69.3	1.03	1.30	593	901	66
7–14	60.4	66.3	1.18	1.26	713	835	85
14–21	62.6	64.9	1.09	1.52	682	986	69
L.S.D. (0.05)	5.9		—		131		
Carp Clay Loam (R)							
0– 7	44.5	48.8	1.34	1.37	596	669	89
7–14	47.9	52.5	1.10	1.25	527	656	80
14–21	52.1	54.8	1.09	1.28	568	701	81
L.S.D. (0.05)	6.2		—		109		
Carp Clay Loam (S)							
0– 8	52.5	59.5	1.70	2.16	893	1285	70
8–15	52.3	52.4	1.96	2.18	1025	1142	90
15–24	51.3	52.2	2.39	2.59	1226	1352	91
L.S.D. (0.05)	6.5		—		142		
Grenville Loam							
0– 6	50.7	51.9	0.84	1.29	426	670	64
6–17	34.0	38.2	0.78	1.06	265	405	65
17–24	41.5	53.1	0.73	1.12	303	595	51
L.S.D. (0.05)	4.2		—		90		
Castor Silt Loam							
0– 6	14.9	38.2	0.58	1.14	86	435	20
6–12	10.6	30.3	0.52	1.30	55	394	14
12–20	17.8	33.4	0.60	0.91	107	304	35
L.S.D. (0.05)	3.1		—		50		
Rubicon Sand							
0– 6	15.5	17.7	1.77	2.50	274	443	62
6–12	11.3	10.7	1.74	2.35	197	251	79
12–18	18.5	20.7	1.38	2.46	255	509	50
L.S.D. (0.05)	2.9		—		51		

soils, and of Castor silt loam and Rubicon sand when taken below a depth of 12 inches, produced yields that were similar to or slightly higher than those obtained on the corresponding surface samples. Samples taken just below the surface produced significantly lower yields than the corresponding surface or lower subsurface samples of Grenville loam, Castor silt loam and Rubicon sand. Application of potassium increased the yields on Castor silt loam significantly but had no pronounced effect on yield on the other soils.

Addition of potassium increased the concentration of potassium in the crop. The average content was 1.21 per cent for the P treatment as compared with 1.61 per cent for PK.

Comparison of the data for potassium (Table 5) with those for phosphorus (Table 4) shows that the influence of depth of sampling and fertilizer treatment on uptake values was much less pronounced for potassium than for phosphorus. With addition of phosphorus only, the amounts of potassium removed from the middle layer of Rubicon sand and from both subsurface layers of Grenville loam were significantly lower than the amounts taken up from the corresponding surface layers. Potassium uptake from these three subsurface samples varied from 62 to 72 per cent of the uptake from corresponding surface samples. The plants grown with the P treatment removed a significantly higher amount of potassium from the lower subsurface than from the surface sample of Carp clay loam (S). For the remainder of the experiment, the differences in potassium uptake between surface and subsurface samples receiving no potassium in the fertilizer were not significant.

Application of potassium increased the potassium uptake values consistently. The differences were significant except in four instances. When the uptake for the P treatment, expressed as a percentage of that for PK, was used to assess the potassium-supplying power of the soils, the clay loams were the best and Castor silt loam was the poorest. Grenville loam and Rubicon sand were intermediate in their capacity to supply potassium to the crop. Although variations occurred between the percentage values for samples taken at different depths, there was little evidence of any pronounced differences between the potassium-supplying power of the subsurface and surface soil.

Relationship of Greenhouse Results and Chemical Tests for P and K

For purposes of comparison with the soil test values, the greenhouse results were considered in terms of the uptake for the K or P treatment expressed as a percentage of the uptake for PK.

The results from soil tests and from the greenhouse experiment relating to phosphorus supply in the soils at different depths were in poor agreement. While the greenhouse results indicated a greater supply of phosphorus in the surface than in the subsurface layers of most of the soils, the values for acid-soluble phosphorus in all but one soil increased consistently with depth. Although the amounts of inorganic $NaHCO_3$-soluble phosphorus for three of the soils were higher in the surface than in the subsurface samples in agreement with greenhouse results, the relationship between these two sets of values for Carp clay loam (R), Castor silt loam and Rubicon sand was poor.

The absence of any pronounced variation in exchangeable potassium with depth as shown in four of the soils was in agreement with greenhouse results. But the contrasting trends for increase in per cent potassium saturation and decrease in water-soluble potassium with depth were not reflected in the data from the greenhouse experiment.

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